



Investigation of Corrosion in LPG Units: A Review of Causes, Mechanisms, and Mitigation Strategies

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Article info

Received: 02.03.2025

Accepted: 20.05.2025

Available Online: 21.05.2025

Checked for Plagiarism: Yes

Keywords:

LPG units, corrosion, hydrogen sulfide, carbon dioxide, sweet corrosion.

ABSTRACT

Corrosion in Liquefied Petroleum Gas (LPG) units poses significant challenges to the safety, reliability, and efficiency of refining and petrochemical operations. These units operate under high pressure and varying temperature conditions, exposing metallic equipment to aggressive environments containing corrosive agents such as hydrogen sulfide (H₂S), carbon dioxide (CO₂), moisture, and trace acidic compounds. The interaction of these substances with carbon steel and other commonly used materials leads to various corrosion phenomena, including uniform corrosion, localized pitting, and stress corrosion cracking. Sweet corrosion, primarily driven by CO₂, results in the formation of iron carbonate protective scales under certain conditions, while sour corrosion induced by H₂S forms brittle iron sulfide layers that exacerbate metal degradation. Additionally, microbiologically influenced corrosion (MIC) caused by sulfate-reducing bacteria further complicates corrosion management in LPG storage facilities. Effective corrosion control requires a multifaceted approach involving material selection, chemical inhibitors, protective coatings, and rigorous operational monitoring. Electrochemical techniques such as Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR) are widely employed for real-time corrosion rate assessment. Despite advancements in mitigation strategies, corrosion remains a critical concern due to its impact on operational costs, safety hazards, and equipment lifespan. Continued research and development are essential to optimize corrosion prevention methods and enhance the durability of LPG processing and storage infrastructure.

Introduction

Corrosion in LPG units primarily arises due to the presence of corrosive agents such as hydrogen sulfide (H₂S), carbon dioxide (CO₂), water, and trace acidic components. These substances can accelerate electrochemical reactions on metal surfaces, leading to uniform corrosion, pitting, or localized attacks. The presence of moisture combined with CO₂ and H₂S often results in sweet and sour corrosion mechanisms, respectively. Sour corrosion, associated with H₂S, poses significant risks due to the formation of iron sulfide scales that can be porous and non-protective, facilitating continuous metal loss [1].

Corrosion in LPG units involves the gradual degradation of metallic materials due to chemical or electrochemical reactions with their environment. The presence of impurities such as hydrogen sulfide (H₂S), carbon dioxide (CO₂), moisture, and acidic components in LPG and its processing environment promotes various corrosion mechanisms [2]. These factors create a complex corrosive milieu that can lead to uniform corrosion, localized pitting, crevice corrosion, and stress corrosion cracking. Each of these corrosion types poses distinct threats to the integrity of equipment such as pipelines, storage tanks, heat exchangers, and pressure vessels,

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potentially resulting in leaks, failures, and costly downtime [3].

Among the corrosive agents, H₂S and CO₂ are particularly notorious in LPG processing. Hydrogen sulfide leads to sour corrosion, which can induce sulfide stress cracking (SSC) and hydrogen embrittlement in susceptible materials. The presence of CO₂ causes sweet corrosion through the formation of carbonic acid when dissolved in water, accelerating the degradation of carbon steel surfaces. Moisture is a critical factor because it acts as an electrolyte enabling electrochemical corrosion reactions. Even trace amounts of water can significantly influence corrosion rates and mechanisms, emphasizing the importance of controlling moisture content in LPG units [4].

The materials commonly employed in LPG units include carbon steels, low-alloy steels, and corrosion-resistant alloys. Carbon steel remains the predominant choice due to its mechanical properties and cost-effectiveness; however, its vulnerability to corrosion necessitates protective strategies. Corrosion-resistant alloys, including stainless steels and nickel-based alloys, offer enhanced resistance but come at a higher economic cost, limiting their widespread use. Consequently, understanding the corrosion behavior of carbon steel and optimizing mitigation techniques are primary concerns in the LPG industry [5].

To combat corrosion, several approaches are employed. Chemical inhibitors are often injected to form protective films on metal surfaces, reducing the electrochemical activity. These inhibitors must be carefully selected based on the chemical composition of the LPG and the operating conditions to ensure effectiveness without contaminating the product. Protective coatings and linings also provide physical barriers against corrosive species, especially in storage tanks and pipelines. Additionally, proper material selection and design modifications can minimize areas prone to corrosion, such as stagnant zones and crevices [6]. Monitoring and assessment of corrosion rates are crucial for effective maintenance and prevention strategies. Electrochemical techniques, such as Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR), have gained prominence for their ability to provide real-time, non-destructive evaluation of corrosion processes. These methods help operators detect early signs of corrosion, enabling timely interventions before severe damage occurs. In addition to electrochemical methods, regular inspection, ultrasonic testing, and corrosion coupons are integral parts of comprehensive corrosion management programs [7].

Microbiologically Influenced Corrosion (MIC) represents another significant challenge in LPG storage and handling facilities. Sulfate-reducing bacteria (SRB) and other microbial populations can

thrive in water films and sludge deposits, producing corrosive metabolites such as H₂S. MIC can cause localized pitting and accelerate overall corrosion rates, often going undetected until substantial damage occurs. Addressing MIC requires stringent monitoring of microbial activity and the application of biocides or other control measures.

The consequences of corrosion in LPG units are multifaceted. Equipment failure due to corrosion can lead to leaks, fires, and explosions, posing safety hazards to personnel and the environment. Furthermore, corrosion-related downtime and maintenance increase operational costs and reduce plant availability. Regulatory compliance concerning environmental and safety standards also demands rigorous corrosion control. Thus, improving the understanding of corrosion mechanisms and developing robust mitigation strategies are vital for the sustainable operation of LPG facilities [8].

In recent years, research efforts have focused on developing advanced materials with better corrosion resistance, more efficient corrosion inhibitors, and sophisticated monitoring technologies. Nanotechnology and smart coatings are emerging fields showing promise in enhancing corrosion protection. Furthermore, computational modeling and simulation of corrosion processes provide insights into predicting corrosion behavior under varying conditions, aiding in proactive maintenance planning [9].

In conclusion, corrosion remains a persistent and complex issue in LPG units, driven by chemical, physical, and biological factors inherent in their operating environments. A comprehensive approach encompassing material science, chemical treatment, monitoring, and operational control is essential to mitigate corrosion risks. Continued innovation and research will play a pivotal role in enhancing the reliability, safety, and economic viability of LPG processing and storage operations worldwide.

Corrosion Mechanisms

The primary corrosion mechanisms in LPG units include:

- ✓ **Sweet Corrosion:** Caused mainly by CO₂, it leads to the formation of iron carbonate (FeCO₃) scales. Under favorable conditions (high temperature, low flow velocity), these scales may become protective; however, breakdown of these layers leads to rapid corrosion.
- ✓ **Sour Corrosion:** Associated with H₂S presence, it promotes the formation of iron sulfide layers that are often brittle and porous, contributing to localized corrosion and stress corrosion cracking.
- ✓ **Microbiologically Influenced Corrosion (MIC):** In some LPG storage environments,

sulfate-reducing bacteria (SRB) can thrive, producing H₂S and accelerating corrosion rates.

Materials and Susceptibility

Carbon steel is widely used in LPG units due to cost-effectiveness and mechanical properties. However, its susceptibility to corrosion necessitates monitoring and mitigation. Stainless steels and corrosion-resistant alloys (CRAs) are alternatives in critical areas but come at higher costs [10].

Corrosion Monitoring and Mitigation

Effective corrosion management includes:

- ✓ **Chemical Inhibitors:** Use of corrosion inhibitors tailored for LPG environments to reduce corrosion rates.
- ✓ **Coatings and Linings:** Application of protective barriers to isolate metal surfaces from corrosive agents.
- ✓ **Material Selection:** Employing suitable alloys resistant to H₂S and CO₂ corrosion.
- ✓ **Operational Controls:** Maintaining low moisture content and controlling temperature and pressure conditions.
- ✓ **Monitoring Techniques:** Electrochemical methods such as Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR) are utilized to assess corrosion rates in real-time.

Discussion on Corrosion in LPG Units

Liquefied Petroleum Gas (LPG) units, encompassing storage, processing, and transportation systems, are fundamental components of the petrochemical and energy industries. These units operate under conditions that make them highly susceptible to corrosion, a process that jeopardizes equipment integrity, operational safety, and economic efficiency. Understanding the causes, mechanisms, and control methods of corrosion within LPG units is therefore essential for maintaining system reliability and prolonging service life [11].

Causes of Corrosion in LPG Units

Corrosion in LPG units primarily results from the interaction of metals with corrosive species present in the environment. Key contributors include hydrogen sulfide (H₂S), carbon dioxide (CO₂), water (moisture), and trace acidic compounds such as organic acids. Each of these agents plays a distinctive role in accelerating corrosion processes. Hydrogen sulfide is particularly detrimental as it induces sour corrosion, characterized by the formation of iron sulfide layers that are typically porous and non-protective. This results in continuous metal dissolution and can lead to severe forms of degradation, including sulfide stress cracking (SSC) and hydrogen embrittlement. CO₂, on the other hand, contributes to sweet corrosion by

dissolving in water to form carbonic acid, which lowers the pH and accelerates the electrochemical corrosion of carbon steel surfaces [12].

Moisture presence is critical since it acts as an electrolyte, facilitating the electrochemical reactions underlying corrosion. Even trace amounts of water in LPG units can drastically enhance corrosion rates. Furthermore, impurities and operational factors such as temperature, pressure, and flow velocity influence the severity and nature of corrosion.

Corrosion Mechanisms

The primary corrosion mechanisms identified in LPG units include sweet corrosion, sour corrosion, microbiologically influenced corrosion (MIC), and flow-accelerated corrosion (FAC) [13].

1- Sweet Corrosion: This type arises from the presence of CO₂ and is common in pipelines and vessels exposed to CO₂-containing LPG. The CO₂ dissolves in water to form carbonic acid, which attacks steel surfaces. Under favorable conditions such as elevated temperature and low flow velocity protective iron carbonate (FeCO₃) scales may form, which reduce corrosion rates. However, disruption of these protective layers due to mechanical or chemical factors can lead to rapid corrosion.

2-Sour Corrosion: H₂S presence results in sour corrosion, a more aggressive form characterized by iron sulfide scale formation. These scales are often porous and non-adherent, failing to protect the underlying metal. Sour corrosion is particularly concerning because it can induce sulfide stress cracking, a brittle failure mode influenced by tensile stresses and hydrogen ingress into the metal lattice.

3-Microbiologically Influenced Corrosion (MIC): In some LPG storage environments, microorganisms such as sulfate-reducing bacteria (SRB) thrive in water films or sludge deposits. These bacteria metabolize sulfate ions, producing H₂S as a byproduct, which exacerbates sour corrosion. MIC leads to localized pitting and can cause unexpected failures if not properly monitored and controlled [14].

4-Flow-Accelerated Corrosion (FAC): High flow velocities in pipelines can erode protective oxide layers, exposing fresh metal surfaces to corrosive agents. This results in increased corrosion rates and potential thinning of pipeline walls, which compromises structural integrity.

Materials Susceptible to Corrosion

Carbon steel is extensively used in LPG units due to its mechanical properties and cost-effectiveness. However, its vulnerability to various corrosion mechanisms necessitates the application of mitigation techniques. Corrosion-resistant alloys (CRAs) such as stainless steels and nickel-based alloys provide superior resistance to sour and sweet corrosion but are considerably more expensive,

limiting their application to critical components or high-risk areas.

Material selection must consider not only corrosion resistance but also mechanical properties, weldability, and economic factors. Moreover, environmental conditions, including H₂S and CO₂ concentrations, temperature, and flow dynamics, dictate the suitability of materials in specific sections of LPG units [15].

Corrosion Monitoring Techniques

Early detection and continuous monitoring of corrosion are paramount for effective maintenance. Electrochemical methods, such as Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR), have been widely adopted to assess corrosion rates in real-time. These non-destructive techniques provide insight into the kinetics of corrosion reactions and the integrity of protective films.

Additionally, traditional methods including weight loss coupons, ultrasonic thickness measurements, and visual inspections remain valuable. Advances in sensor technology have introduced online corrosion monitoring systems capable of providing operators with immediate feedback, enabling timely intervention before significant damage occurs [16].

Corrosion Mitigation Strategies

Mitigating corrosion in LPG units requires a multi-pronged approach:

1- Chemical Inhibitors: Corrosion inhibitors are added to the LPG stream or water phase to form protective films on metal surfaces, reducing the electrochemical activity. Selecting inhibitors compatible with the chemical composition of LPG and operating conditions is essential to prevent contamination and maintain product quality.

2-Protective Coatings and Linings: Applying coatings or linings to internal surfaces of tanks, pipelines, and vessels isolates metals from corrosive agents. These barriers can be organic (epoxy, polyurethane) or inorganic (ceramic, metallic). Proper surface preparation and application techniques are critical to coating performance.

3-Material Selection and Design: Using corrosion-resistant materials in high-risk zones, optimizing

pipeline routing to minimize stagnant zones, and designing for proper drainage and moisture control help reduce corrosion potential [17].

4-Operational Controls: Controlling moisture levels, maintaining appropriate temperature and pressure, and minimizing pressure fluctuations reduce corrosion-driving factors. Regular purging and drying of LPG systems help keep moisture content low.

5-Microbial Control: To counter MIC, biocides are employed, and monitoring of microbial populations is conducted regularly. Sludge removal and water treatment further limit microbial growth.

6-Cathodic Protection: This electrochemical method applies an external current to suppress anodic dissolution, protecting buried or submerged components from corrosion [18].

Impact of Corrosion on LPG Units

The repercussions of corrosion in LPG units extend beyond material degradation. Leaks due to corrosion breaches can cause fires, explosions, and environmental contamination, posing safety risks to personnel and surrounding communities. Corrosion-induced failures also lead to costly shutdowns, repair expenses, and regulatory penalties.

Hence, effective corrosion management contributes not only to operational reliability but also to environmental stewardship and corporate responsibility [19].

Future Directions and Research

Emerging technologies in corrosion protection, such as nanostructured coatings, smart inhibitors, and advanced sensors, show promise in enhancing corrosion resistance and monitoring capabilities. Computational modeling and predictive analytics are increasingly used to forecast corrosion behavior, optimize maintenance schedules, and reduce unplanned outages (Table 1).

Research continues to focus on understanding complex corrosion mechanisms under multiphase flow conditions and developing tailored mitigation strategies for evolving LPG compositions and operational scenarios [20].

Table 1. Literature review [21]

Article Title	Corrosion Type	Methodology	Key Findings
Corrosion behavior of carbon steel in LPG environments: Influence of H ₂ S and CO ₂ gases	Sweet and sour corrosion	Electrochemical tests, weight loss	H ₂ S accelerates sour corrosion; CO ₂ forms protective scales under certain conditions
Investigation of corrosion mechanisms in LPG storage tanks under varying pressure and temperature	Uniform and localized corrosion	Metallography, EIS	Higher pressure increases corrosion rates; temperature impacts scale formation

Effect of inhibitors on corrosion control in LPG transport pipelines	General corrosion	Lab inhibitor screening, field trials	Certain inhibitors reduced corrosion rate by over 70%
Microbiologically influenced corrosion in LPG storage facilities: Case studies and mitigation	MIC	Microbial analysis, corrosion coupons	SRB presence linked to localized pitting; biocides effective in control
Corrosion rate prediction in LPG processing units using electrochemical impedance spectroscopy	Electrochemical corrosion	EIS monitoring	EIS effective for early corrosion detection and rate prediction
Sulfide stress cracking susceptibility of pipeline steels in sour LPG environments	SSC	Mechanical testing, fractography	Higher H ₂ S concentration increases SSC risk in carbon steels
Influence of moisture content on CO ₂ corrosion in LPG pipelines	Sweet corrosion	Controlled humidity tests	Moisture significantly increases corrosion rates in CO ₂ environments
Development of nanocoatings for corrosion protection in LPG units	Protective coating	Synthesis and performance testing	Nanocoatings enhanced corrosion resistance by forming dense barriers
Impact of operating pressure fluctuations on corrosion in LPG vessels	General corrosion	Pressure cycling experiments	Pressure variations cause mechanical damage to protective scales
Evaluation of stainless steel alloys for sour LPG service	Sour corrosion	Field exposure, corrosion rate measurement	Duplex stainless steels show superior resistance to sour corrosion
Electrochemical study of inhibitor mixtures for LPG pipeline corrosion control	Corrosion inhibition	Electrochemical testing	Synergistic effects observed in inhibitor blends improving performance
Effect of temperature on microbiologically influenced corrosion in LPG tanks	MIC	Temperature variation experiments	MIC activity peaks at moderate temperatures; inhibited at high temps
Comparative study of corrosion mechanisms in LPG and natural gas processing units	Various corrosion types	Field sampling, lab simulation	LPG units more prone to sour corrosion due to higher H ₂ S content
Application of corrosion sensors for real-time monitoring in LPG units	Corrosion monitoring	Sensor development and testing	Sensors provided accurate early warning for corrosion onset
Effectiveness of cathodic protection in LPG storage tanks	Electrochemical corrosion control	Field cathodic protection systems	Cathodic protection significantly reduced corrosion rates
Study on pitting corrosion behavior of carbon steel in sour LPG environments	Pitting corrosion	Potentiodynamic polarization	Localized pitting enhanced by H ₂ S presence and surface defects
Influence of acid gas impurities on corrosion of LPG transport pipelines	Sweet and sour corrosion	Gas composition analysis and corrosion testing	Mixed acid gases increase corrosion complexity and rate
Impact of flow velocity on corrosion in LPG pipelines	Flow-accelerated corrosion	Flow loop experiments	Higher velocities increase erosion-corrosion risk
Corrosion mitigation strategies for aging LPG infrastructure	Various corrosion types	Review of mitigation techniques	Integrated approaches combining inhibitors, coatings, and monitoring most effective
Role of hydrogen embrittlement in failure of LPG pipelines	Hydrogen-induced cracking	Fracture analysis	Hydrogen embrittlement critical in presence of H ₂ S and mechanical stress

Corrosion in Liquefied Petroleum Gas (LPG) units represents a persistent and complex challenge that significantly impacts the safety, reliability, and operational efficiency of refining and petrochemical facilities [22]. The corrosive environments in these units are shaped by the presence of aggressive chemical species such as hydrogen sulfide (H₂S), carbon dioxide (CO₂), moisture, and trace acidic compounds, all of which interact synergistically to accelerate the degradation of metallic components [23]. This multifaceted corrosion phenomenon demands a comprehensive understanding of its underlying mechanisms, contributing factors, and effective control measures to mitigate risks and ensure the longevity of LPG infrastructure [24].

One of the foremost insights gained from recent research and operational experience is the critical role of sour and sweet corrosion mechanisms in LPG units. Sour corrosion, induced by H₂S, leads to the formation of iron sulfide scales that are often porous and non-protective, promoting continuous metal loss and susceptibility to sulfide stress cracking and hydrogen embrittlement [25]. Sweet corrosion, driven primarily by CO₂, involves the generation of carbonic acid in the presence of moisture, resulting in the deterioration of carbon steel surfaces. Both corrosion types present unique challenges, and their severity is influenced by operational parameters such as pressure, temperature, flow velocity, and moisture content [26].

Material selection plays a pivotal role in managing corrosion risks in LPG units. Carbon steel remains the material of choice for many applications due to its favorable mechanical properties and cost-effectiveness. However, its vulnerability to various corrosion forms necessitates the deployment of supplementary protective measures [27]. Corrosion-resistant alloys and stainless steels offer enhanced resistance but involve higher capital expenditure, underscoring the need for strategic allocation of these materials in critical areas subject to aggressive environments. Additionally, the design and maintenance of LPG units must emphasize minimizing stagnant zones, controlling moisture ingress, and avoiding conditions conducive to corrosion acceleration [28].

Corrosion monitoring and detection are indispensable components of an effective corrosion management program. Techniques such as Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization Resistance (LPR) enable real-time assessment of corrosion rates, facilitating proactive maintenance and early intervention [29]. Complementary methods including ultrasonic thickness measurements, corrosion coupons, and visual inspections provide comprehensive evaluation of equipment condition [30]. Moreover, advancements in sensor technology and data analytics hold promise for enhancing predictive

maintenance capabilities and reducing unplanned downtime [31].

Mitigation strategies encompass a combination of chemical, physical, and operational approaches tailored to the specific conditions of LPG units. The use of corrosion inhibitors, carefully selected to match the chemical milieu, can significantly reduce corrosion rates by forming protective films on metal surfaces [32]. Protective coatings and linings offer physical barriers that isolate equipment from corrosive agents, although their effectiveness depends heavily on proper application and maintenance [33]. Operational controls aimed at reducing moisture levels, stabilizing temperature and pressure, and preventing pressure fluctuations further contribute to minimizing corrosion potential. Addressing microbiologically influenced corrosion through biocide application and microbial monitoring is also essential in preventing localized pitting and structural failures [34].

The consequences of corrosion extend beyond material degradation, encompassing safety hazards, environmental risks, and economic losses. Corrosion-induced leaks can lead to fires, explosions, and hazardous emissions, jeopardizing personnel safety and environmental integrity. Additionally, corrosion-related maintenance and repairs incur significant costs and may result in operational disruptions. Therefore, a holistic corrosion management approach not only safeguards physical assets but also aligns with regulatory compliance and corporate social responsibility [35].

Looking forward, ongoing research and technological innovation are crucial to advancing corrosion control in LPG units. The development of advanced materials with superior corrosion resistance, such as nanostructured coatings and smart alloys, offers promising avenues for enhancing equipment durability [36]. Emerging monitoring technologies integrating sensors, automation, and machine learning enable more precise and timely detection of corrosion phenomena. Furthermore, computational modeling and simulation tools contribute to understanding corrosion dynamics and optimizing maintenance strategies.

Conclusion

Corrosion in LPG units remains a multifaceted challenge influenced by chemical composition, environmental conditions, material properties, and operational factors. A comprehensive understanding of corrosion causes and mechanisms, combined with vigilant monitoring and integrated mitigation strategies, is essential for safeguarding LPG infrastructure. Continued innovation and research will be key to improving the safety, durability, and economic viability of LPG processing and storage systems worldwide.

Corrosion in LPG units remains a complex challenge due to the diverse chemical and physical factors influencing material degradation. Advances in corrosion monitoring technologies and inhibitor formulations continue to improve equipment lifespan and safety. Nonetheless, ongoing research is essential to develop cost-effective, reliable corrosion control strategies tailored for the unique environments of LPG processing and storage.

In summary, corrosion in LPG units is a multifactorial problem driven by chemical, mechanical, and biological factors. Its effective management demands an integrated approach combining material science, chemical treatment, monitoring, and operational best practices. Continuous innovation, informed by rigorous research and field data, is essential to mitigate corrosion risks, enhance safety, and improve the economic performance of LPG processing and storage facilities. By prioritizing corrosion control, the industry can ensure the resilience and sustainability of critical infrastructure that supports global energy needs.

Disclosure Statement

No potential conflict of interest reported by the authors.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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