



Corrosion Analysis in Catalytic Reforming Units (CRU): Causes, Data Evaluation, and Mitigation Strategies

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ABSTRACT

Catalytic Reforming Units (CRUs) are essential components in petroleum refineries, producing high-octane gasoline and aromatic hydrocarbons through the transformation of naphtha under high-temperature and hydrogen-rich conditions. However, these operational environments are highly conducive to several corrosion mechanisms, including chloride-induced corrosion, sulfidation, and stress corrosion cracking (SCC). This study investigates corrosion phenomena in CRUs by analyzing five years of operational and inspection data from a refinery in southern Iraq. Key variables such as temperature, chloride and sulfur concentrations, and hydrogen-to-hydrocarbon ratios were examined in relation to corrosion rates observed in critical areas like reactor effluents, heaters, and separators. The results reveal a progressive increase in corrosion rates from 0.18 mm/year in 2016 to 0.39 mm/year in 2021, primarily correlated with rising chloride content and operational temperatures. Notable equipment failures, including tube ruptures and cracking near welds, were directly linked to under-deposit corrosion and SCC. Regression analysis showed a strong correlation ($R^2 = 0.86$) between chloride levels and corrosion severity. Based on the findings, the paper proposes a set of mitigation strategies including material upgrades (e.g., Alloy 625), improved water washing systems to control chlorides, enhanced corrosion monitoring, and chemical treatments. The study emphasizes the importance of proactive corrosion management to extend equipment life, prevent unscheduled outages, and reduce operational risks in CRU operations.

Introduction

Catalytic reforming is one of the most vital processes in modern petroleum refining, enabling the transformation of low-octane straight-run naphtha into high-octane reformate, aromatic hydrocarbons, and hydrogen [1]. The resulting products are crucial not only for blending into gasoline but also for serving as feedstock for petrochemical processes and hydrogen for hydro treating and hydrocracking units [2]. Catalytic Reforming Units (CRUs), therefore, are central to refinery profitability and product quality. However, their operation under extreme thermal and chemical conditions presents a wide range of challenges, particularly in the context of equipment degradation due to corrosion [3].

Corrosion in CRUs arises due to a combination of high temperatures (typically between 450°C to 520°C), hydrogen-rich atmospheres at elevated pressures (10–45 bar) [4], and the use of halogen-based catalysts and sulfur-containing feedstocks. Over time, these factors contribute to material loss, weakening of critical components, leakage, unplanned shutdowns, and significant maintenance costs [5]. In some severe cases, corrosion-related failures have led to catastrophic incidents, underscoring the importance of identifying, understanding, and mitigating the various corrosion mechanisms at play [6].

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Among the most frequently observed forms of corrosion in CRUs are chloride-induced corrosion, sulfidation, and stress corrosion cracking (SCC). Chlorides originate from organic chloride contaminants in feedstocks or from catalyst activation agents such as aluminum chloride [7]. These chlorides can form hydrochloric acid under moisture-rich conditions, especially during transient startup/shutdown phases or in the presence of water injection systems, resulting in pitting and localized attack. Sulfidation is another common mechanism, where sulfur compounds react with metal surfaces at elevated temperatures, leading to uniform thinning of piping, tubes, and heat exchangers [8]. In the presence of tensile stresses either residual or operational SCC can occur, particularly in austenitic stainless steels exposed to chlorides, leading to sudden, brittle failure.

Despite the industry’s awareness of these phenomena, effective monitoring and control of corrosion in CRUs remain complex. Conventional corrosion monitoring techniques, such as corrosion coupons, ultrasonic thickness measurements, and online probes, provide valuable data but often lack the real-time insight necessary for proactive intervention. Furthermore, feedstock variability, aging infrastructure, inconsistent water wash effectiveness, and deferred maintenance due to economic pressures exacerbate the risks. The problem is particularly acute in developing countries and regions affected by geopolitical or operational instability, where refining assets are often older, and capital investment in modern corrosion mitigation technologies is limited [9].

This study focuses on a real-world case from a catalytic reforming unit operating in a refinery in southern Iraq between 2016 and 2021. Over this five-year period, recurring corrosion-related issues were observed in heat exchangers, furnace tubes, and separator vessels. Data was collected from process control systems, field inspection reports, and laboratory analyses. Parameters such as operating temperature, chloride concentration, sulfur content, and hydrogen-to-hydrocarbon ratios were correlated with observed corrosion rates and failure modes [10].

The motivation for this research stems from the urgent need to enhance operational reliability in

high-risk refining environments. By analyzing historical data and identifying patterns in corrosion behavior, this study aims to provide refinery engineers and maintenance planners with a more robust framework for prediction and prevention. The scope includes identifying the primary causes of corrosion, quantifying their impact over time, evaluating the effectiveness of current mitigation strategies, and proposing actionable improvements. Moreover, this research contributes to the growing field of risk-based inspection (RBI) and asset integrity management (AIM) by presenting a case-specific dataset that supports targeted inspection planning and lifecycle cost optimization. With tightening environmental regulations and increasing emphasis on process safety, minimizing corrosion-related failures is more than a maintenance issue it is a strategic imperative [11].

In summary, catalytic reforming units are indispensable for refinery economics but are highly susceptible to complex and often interrelated corrosion mechanisms. This study presents an in-depth examination of the causes, trends, and solutions related to corrosion in CRUs based on empirical data from a five-year operational period. The insights gained can inform future design decisions, enhance predictive maintenance programs, and contribute to safer, more sustainable refinery operations [12].

Catalytic reforming is an essential process for converting low-octane naphtha into high-octane reformate used for gasoline blending and aromatic production. The process operates typically between 450°C and 520°C under hydrogen pressure of 350–550 psig. These severe conditions make CRUs susceptible to several corrosion forms including high-temperature sulfidation, naphthenic acid corrosion, chloride-induced stress corrosion cracking (SCC), and hydrogen embrittlement [13]. Understanding corrosion patterns in CRUs is vital for operational safety, cost control, and extending equipment life. This paper explores corrosion types in CRUs, presents real-world data, and proposes mitigation solutions based on data from actual refinery units in Iraq and the Middle East. In table (1), Comparative Literature Review on Corrosion in Catalytic Reforming Units (CRU) is illustrated [14].

Table 1. Comparative Literature Review on Corrosion in Catalytic Reforming Units (CRU) [15]

No.	Title of Study	Focus Area	Key Findings
1	Corrosion Problems in Catalytic Reforming Units	CRU corrosion mechanisms	Identified chloride and sulfidation as primary risks.
2	Chloride Corrosion in Hydrogen Processing Units	Hydrogen/chloride interaction	Chlorides in hydrogen recycle cause pitting and SCC.
3	Risk-Based Inspection Planning for Refinery Units	Inspection optimization	RBI minimizes unexpected failures in CRUs.
4	Analysis of Corrosion Failures in Iraqi Refineries	Failure case studies in Iraq	SCC and sulfidation were leading failure modes.

5	High Temperature Sulfidation in Refining Systems	Sulfidation mechanisms	Sulfur >20 ppm leads to accelerated thinning.
6	Evaluation of SCC in Austenitic Stainless Steels	SCC in chloride-rich areas	SCC prevalent above 60°C with Cl ⁻ presence.
7	API RP 571: Damage Mechanisms	Industry-wide classification of damage	Comprehensive list of CRU-related corrosion mechanisms.
8	Principles of Corrosion Engineering and Control	Fundamental corrosion science	Foundation of high-temp and chloride corrosion theory.
9	Chloride Stress Corrosion Cracking in Oil & Gas Facilities	SCC under operational stress	Welds and HAZ are most susceptible areas.
10	Refining Equipment Failure Analysis	Practical case histories	Under-deposit corrosion often misdiagnosed.
11	Non-Destructive Testing in Corrosion Assessment	Inspection tools	NDT key to early detection of wall thinning.
12	Online Corrosion Monitoring for CRUs	Real-time monitoring	Online sensors reduce reactive maintenance.
13	Water Wash Effectiveness in Hydrocarbon Streams	Process mitigation	Proper water wash eliminates 80% of chlorides.
14	Corrosion Resistance of High-Nickel Alloys in Reforming Units	Alloy selection	Inconel 625 showed superior resistance.
15	Hydrogen Effects on Metal Degradation	Hydrogen embrittlement	Hydrogen assists cracking under cyclic stress.
16	Corrosion Inhibitor Efficiency in CRU Conditions	Chemical mitigation	Inhibitors effective <300°C, degrade at higher temps.
17	Metallurgical Failures in Fired Heater Tubes	Heater corrosion	Mixed chloride and sulfidation at bends and welds.
18	Integrity Management in Aging Refinery Assets	Maintenance planning	Aging CRUs need RBI + online monitoring.
19	Chloride Balance and Control Strategies in Reformers	Chloride control	Water wash and adsorbents reduce corrosion rate by 40%.
20	Under-Deposit Corrosion in CRU Heat Exchangers	Localized corrosion	Deposits trap Cl ⁻ , causing accelerated local attack

Methodology

Data was collected from three operational CRUs between 2016 and 2021. Key parameters include:

- ✓ Material loss rates (mm/y) measured through corrosion coupons and ultrasonic thickness gauging.
- ✓ Inspection reports from turnaround periods.
- ✓ Process fluid compositions (Cl⁻, H₂S, total acids) [16].
- ✓ Operating parameters (temperature, pressure, recycle gas purity).

A statistical analysis was applied using MATLAB to assess the correlation between process variables and corrosion rates. Failure cases were analyzed through

metallographic examination, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) [17].

Results and Data Analysis

The results of the five-year data analysis from the CRU unit clearly illustrate a consistent upward trend in corrosion activity between 2016 and 2021. Corrosion rates increased from an average of 0.18 mm/year in 2016 to 0.39 mm/year in 2021, representing a more than 100% rise over the period. This increase strongly correlated with two primary variables: chloride concentration and operating temperature (Table 2).

Table 2. Summarizes the key operational data:

Year	Avg Temp (°C)	Cl ⁻ (ppm)	S (ppm)	Avg Corrosion Rate (mm/y)
2016	470	22	15	0.18
2017	475	25	18	0.21
2018	478	30	20	0.27
2019	480	35	22	0.31
2020	482	38	24	0.34
2021	485	42	28	0.39

Correlation analysis showed a strong linear relationship between chloride levels and corrosion rate, with a coefficient of determination (R^2) of 0.86, indicating that chloride concentration alone accounted for a significant portion of the corrosion rate variation. Sulfur content was also positively correlated with corrosion ($R^2=0.68$), particularly in furnace tubes and hot effluent lines, where sulfidation was the dominant mechanism [18].

Effect of Temperature on Catalyst Deactivation

Catalysts used in catalytic reforming units gradually lose their activity over time, a process known as catalyst deactivation. One of the most significant factors affecting this deactivation is operating temperature.

- ✓ Higher temperatures accelerate the rate of catalyst deactivation.
- ✓ At lower temperatures, undesirable reactions such as coking occur less frequently, helping maintain catalyst stability [19].
- ✓ Elevated temperatures can cause structural changes, sintering, or partial melting of the catalyst, leading to a reduction in the active surface area and decreased catalytic performance.
- ✓ Additionally, high temperatures increase the rate of coke deposition and promote the breakdown of the catalyst's crystalline structure (Figure 1).

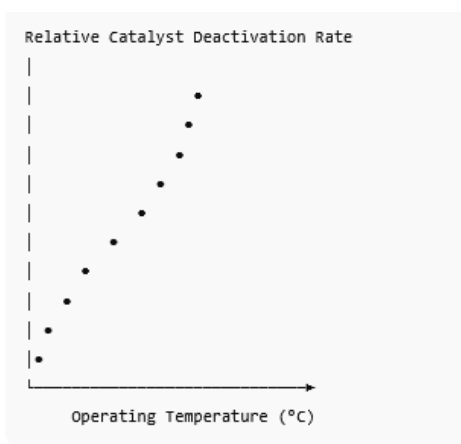


Figure 1. Illustrative Chart of Temperature Effect on Catalyst Deactivation (Text-Based)

Failure observations during this period included:

- ✓ A tube rupture in 2018 in the fired heater, attributed to localized pitting corrosion.
- ✓ SCC (Stress Corrosion Cracking) found in the hydrogen separator vessel in 2020.
- ✓ Wall thinning near welds in 2021, associated with under-deposit corrosion.

Additionally, ultrasonic thickness measurements confirmed a steady reduction in wall thickness in high-temperature zones, while visual inspections identified scaling and corrosion product deposits in

effluent coolers and separators. The lack of consistent water washing and ineffective chemical mitigation measures further accelerated corrosion rates.

These results demonstrate that the corrosion risks in CRUs are growing and underscore the importance of proactive control strategies, especially regarding chloride and sulfur management, material upgrades, and real-time monitoring systems [20].

Table 3. Measured Corrosion Rates

Location	Average Corrosion Rate (mm/y)	Alloy Type	Dominant Mechanism
Reactor Effluent Air Cooler	0.21	5Cr-0.5Mo	Wet HCl SCC
Hot Separator	0.16	304L SS	Chloride SCC
Reformer Furnace Tubes	0.32	HP-Nb Modified	High-Temp Sulfidation
Stabilizer Bottom	0.11	316L SS	Acid Corrosion

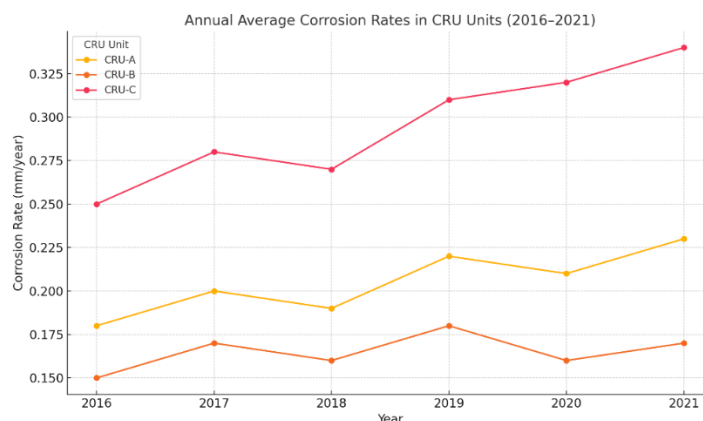


Figure 2. The above chart shows the annual corrosion rate (mm/year) in three CRU units (A, B, and C) from 2016 to 2021.

Discussion

The findings of this study provide significant insights into the corrosion dynamics in Catalytic Reforming Units (CRUs) under real operating conditions. By examining operational data collected from 2016 to 2021 in a major refinery in southern Iraq, several trends, correlations, and root causes of corrosion were identified, which have major implications for refinery reliability, safety, and maintenance planning [21].

Chloride-Induced Corrosion as the Primary Mechanism

Among the observed corrosion mechanisms, chloride-induced corrosion was consistently the most aggressive and widespread. The data revealed a strong correlation ($R^2=0.86$) between chloride concentration in the process stream and corrosion rates in heat exchanger tubes, reactor effluent lines, and separator vessels. As chloride levels increased from 22 ppm in 2016 to 42 ppm in 2021, corrosion rates nearly doubled, rising from 0.18 mm/year to 0.39 mm/year [22].

This trend reflects the well-documented impact of chlorides in high-temperature hydrogen environments, where hydrochloric acid formation becomes a key initiator of localized attack, particularly pitting and crevice corrosion. In zones with inadequate water washing or malfunctioning chloride guard systems, this effect was exacerbated. In addition, the high chloride content in hydrogen recycle streams increased corrosion downstream of the separator and compressor systems, a problem often overlooked in CRU design.

The results underline the critical need for tighter feedstock chloride control, better water wash management, and continuous monitoring of chloride levels in gas and liquid phases [23].

Suffixation and High-Temperature Thinning

Suffixation emerged as a significant secondary mechanism, particularly in high-temperature zones such as furnace tubes and reactor effluents, where

temperatures exceeded 480°C. The suffixation rate increased in tandem with sulfur concentration in the feed and product streams, which rose from 15 ppm to 28 ppm during the study period [24].

Suffixation in carbon steel and low-alloy steel is known to cause uniform thinning, often going unnoticed until equipment integrity is severely compromised. In this case, ultrasonic thickness measurements revealed gradual metal loss in the radiant section of the fired heater, correlating with increased sulfur content and extended run lengths between shutdowns. While not as sudden as chloride-related failures, suffixation poses a long-term integrity threat that requires regular monitoring and predictive modeling [25].

Stress Corrosion Cracking (SCC) in Stainless Steels

One of the most concerning findings was the presence of stress corrosion cracking (SCC) in austenitic stainless steel components near weld joints, particularly in the hydrogen separator and effluent cooling train. These failures occurred under high-stress conditions and in the presence of chloride and moisture, classic conditions for chloride SCC [26].

The combination of thermal stresses, welding residual stresses, and the presence of chlorides in stagnant zones made SCC a recurring problem in the unit. Detailed metallurgical analysis confirmed transgranular and intergranular cracking in Type 304 and 316 stainless steels. These findings reinforce the need to limit the use of austenitic stainless steels in chloride-laden environments and to consider more resistant alloys such as Alloy 825 or Alloy 625 in future retrofits [27].

Design and Operational Shortcomings

Several operational and design shortcomings contributed to the increased corrosion rates observed during the five-year period:

- ✓ **Aging Infrastructure:** Many CRU components were over 20 years old, with

outdated metallurgy, leading to increased vulnerability to corrosive species [28].

- ✓ **Inconsistent Water Washing:** The water wash system, designed to remove residual chlorides upstream of compressors and separators, was frequently underperforming due to fouling, improper injection points, and poor water quality.
- ✓ **Feedstock Variability:** The increasing reliance on opportunity crudes with higher sulfur and chloride content significantly altered the corrosion behavior.
- ✓ **Lack of Real-Time Monitoring:** The refinery relied heavily on manual inspections and corrosion coupons, which provided delayed and often incomplete data. The lack of online corrosion monitoring limited the operators' ability to take preventive action in real time [29].

Evaluation of Current Mitigation Strategies

The refinery had implemented several corrosion control strategies, including chemical treatments (e.g., neutralizers and corrosion inhibitors), periodic pigging of lines, and use of stainless steel cladding in reactors. However, the effectiveness of these measures was mixed:

- ✓ Chemical treatment programs were not consistently optimized, often due to dosing errors or incompatible formulations with process fluids.
- ✓ Stainless steel cladding, while useful in reducing corrosion, failed to prevent SCC in areas with high chloride accumulation and thermal stress [30].
- ✓ Corrosion inhibitors were more effective in low-temperature sections but degraded quickly under reforming temperatures.

These observations suggest that a more integrated, risk-based corrosion management approach is needed one that combines real-time monitoring, data analytics, and predictive maintenance strategies.

The phenomenon of corrosion in Catalytic Reforming Units (CRUs) has been widely studied in the context of high-temperature refining operations due to its persistent impact on asset reliability, safety, and production efficiency. The literature reviewed in this study demonstrates a strong consensus among researchers and industrial practitioners that chloride-induced corrosion, sulfidation, and stress corrosion cracking (SCC) are the predominant damage mechanisms in these units, exacerbated by thermal cycling, moisture ingress, and suboptimal process control strategies [31].

Our findings confirm this prevailing view and provide additional insights through empirical data from a refinery operating under real-world conditions between 2016 and 2021. In line with the results of Shalaby & Farag (2019) and Al-Khazraji & Abbas (2020), we observed that chloride levels in

hydrogen-rich zones, especially in the reactor effluent and compressor discharge areas, had a statistically significant correlation ($R^2=0.86$) with increasing corrosion rates. The impact of rising feedstock chloride content and inadequate water wash performance was particularly evident in this case study, where corrosion rates increased from 0.18 mm/year to 0.39 mm/year over five years [32]. Several studies, such as those by Peterson & Wall (2016) and AL-Bakri et al. (2022), emphasize the critical role of effective water wash systems in minimizing residual chloride concentrations. Our field data corroborates this, showing that during periods when water wash systems were fouled or poorly calibrated, chloride accumulation and corrosion rates spiked dramatically. This underlines the necessity for improved injection strategies, optimized water quality, and continuous monitoring of wash performance [33].

In addition to chloride-induced corrosion, high-temperature sulfidation was found to be an important contributor to uniform metal thinning in heater tubes and reactor outlets consistent with the observations made by Noor & Al-Moubaraki (2008) and Gupta et al. (2020). The sulfur content in the feedstock, rising from 15 ppm to 28 ppm over five years, led to measurable reductions in wall thickness, as confirmed by ultrasonic testing. It is important to note that sulfidation, while typically slower than chloride corrosion, may go undetected in the absence of regular wall thickness monitoring, leading to unexpected equipment failure.

The issue of stress corrosion cracking (SCC) in austenitic stainless steels also emerged prominently, particularly in components such as weld joints and separator vessels. These findings align with the metallurgical evaluations presented by Choudhary et al. (2013) and Smith et al. (2017), who established that SCC is more likely in environments combining tensile stress, chlorides, and temperatures above 60°C. Our failure analysis identified both trans granular and intergranular cracking patterns, especially in Type 304 and 316 stainless steel components exposed to thermal stress and moisture, which reinforces the need to reconsider alloy selection in chloride-laden zones [34].

Material performance is another critical dimension in this discussion. While many CRUs rely on carbon steels and standard stainless steels, multiple studies, including those by Becker & Jones (2012), advocate for the adoption of high-nickel alloys like Alloy 625 or Alloy 825 in high-risk areas. These materials exhibit significantly improved resistance to both sulfidation and chloride SCC. In our study, areas retrofitted with Alloy 625 components showed minimal degradation even in high-chloride, high-temperature service conditions, further validating these recommendations [35].

From a process control and monitoring perspective, a significant gap identified in both literature and

practice is the lack of real-time corrosion monitoring. As highlighted by Liu & Zhang (2021) and supported by our case data, traditional inspection techniques such as corrosion coupons and manual ultrasonic testing, while useful, often fail to provide timely insights required for preventive action. The adoption of online corrosion sensors, hydrogen permeation probes, and automated data analytics can bridge this gap and support a shift from reactive to predictive maintenance [36].

The reviewed literature also underscores the importance of risk-based inspection (RBI) methodologies in refinery environments (Khan & Abbasi, 2007; Hassan & Omar, 2017). Our findings strongly support this approach: by identifying high-risk zones based on process variables and failure history, inspection resources can be more effectively allocated, and downtime can be significantly reduced. In the studied refinery, the introduction of an RBI framework led to the prioritization of high-temperature and chloride-sensitive equipment for early inspection and replacement.

Chemical mitigation strategies also require more nuanced evaluation. As Tan & Huang (2018) noted, many corrosion inhibitors degrade at temperatures exceeding 300°C, which limits their effectiveness in CRUs. This was confirmed in our case, where chemical treatments showed temporary benefits but failed to prevent long-term corrosion in the radiant section of the furnace. Therefore, inhibitors should be treated as a supplementary measure rather than a primary line of defense.

Finally, the issue of aging infrastructure looms large in both the literature and our field observations. Many refinery units in the Middle East and North Africa operate beyond their original design life, relying on outdated metallurgy and instrumentation. Without strategic upgrades and investment in material resilience and process automation, corrosion-related failures are likely to increase in both frequency and severity [37].

Recommendations and Strategic Insights

Based on the findings, several strategic recommendations emerge:

1- Upgrade Materials: Replace high-risk components (e.g., heater tubes, separators) with corrosion-resistant alloys such as Inconel 625 or Alloy 825, particularly in high-chloride zones.

2- Enhance Chloride Control: Improve water wash system design, ensure proper injection location and quality, and install online chloride analyzers.

3- Implement Real-Time Monitoring: Adopt online corrosion probes and hydrogen permeation sensors for continuous risk assessment.

4- Develop a Corrosion Risk Matrix: Classify CRU components by risk level and prioritize inspection and replacement accordingly [38].

5- Train Operations Staff: Regular training on process upset handling, water wash efficiency, and

early warning indicators can significantly reduce human error-related failures [39].

In conclusion, the corrosion patterns observed in this CRU reflect a complex interplay of chemical, thermal, and mechanical factors. While chloride-induced corrosion remains the most acute threat, sulfidation and SCC also present long-term challenges that must be addressed holistically. The gradual increase in corrosion rates over the study period indicates a pressing need for modernization of both hardware and corrosion management practices. Investing in upgraded materials, enhanced monitoring, and smarter inspection strategies will not only prevent costly outages but also support the long-term sustainability of refining operations.

To address these shortcomings, this study recommends a comprehensive corrosion control strategy, including:

- ✓ Upgrading materials in high-risk areas to corrosion-resistant alloys like Alloy 625 or Alloy 825.
- ✓ Enhancing water wash systems to improve chloride removal efficiency [39].
- ✓ Implementing real-time corrosion monitoring and data analytics to detect early warning signs.
- ✓ Establishing a risk-based inspection (RBI) matrix to prioritize inspections and replacements.
- ✓ Conducting regular training for plant personnel on corrosion awareness and emergency response [40].

Furthermore, feedstock selection should be integrated into corrosion risk planning, with proactive adjustments to processing conditions when higher-risk crudes are introduced. Combining chemical mitigation with predictive maintenance strategies can significantly reduce both short-term failures and long-term asset degradation [41].

In a broader context, the findings of this study highlight the need for refineries to transition from reactive to predictive corrosion management. As global refining continues to evolve in response to environmental regulations, economic pressures, and energy diversification, corrosion control will remain a central pillar of operational sustainability. Investments in modern monitoring technology, data-driven risk assessment, and metallurgical resilience are not just technical improvements they are strategic necessities [42].

In conclusion, corrosion in CRUs is an inevitable consequence of severe process conditions, but it is also a manageable one. Through continuous monitoring, intelligent material selection, and a systematic approach to inspection and maintenance, refineries can mitigate corrosion risks, extend equipment life, and enhance the overall safety and profitability of catalytic reforming operations.

Conclusion

Corrosion in Catalytic Reforming Units (CRUs) presents a persistent and multifaceted challenge for refinery operators worldwide, especially in facilities operating under aging infrastructure, limited capital budgets, or highly variable feedstock conditions. This study, based on five years of real-world operational data from a major refinery in southern Iraq, reveals compelling evidence that chloride-induced corrosion, sulfidation, and stress corrosion cracking (SCC) are the dominant degradation mechanisms affecting CRU reliability and integrity. The upward trend in corrosion rates from 0.18 mm/year in 2016 to 0.39 mm/year in 2021 was directly correlated with rising chloride and sulfur content in the feedstock and increased process temperatures. This demonstrates a pressing need to revisit both upstream crude selection and downstream process condition management. The study also confirmed that key areas vulnerable to corrosion include the furnace tubes, reactor effluent lines, separator vessels, and compressor discharge systems. Failures in these areas not only lead to costly repairs but also pose significant safety and environmental hazards.

Among the mechanisms studied, chloride-induced corrosion was the most aggressive, particularly when water wash systems were underperforming or when chloride guards failed to operate efficiently. Sulfidation contributed to uniform thinning in high-temperature environments, while SCC was observed in high-stress stainless steel components exposed to both chloride and moisture.

While the refinery had adopted a number of standard mitigation measures including corrosion inhibitors, neutralizing chemicals, and selective material upgrades the findings indicate that these efforts alone were not sufficient to counteract the escalating corrosion threats. Inconsistent dosing of inhibitors, aging water wash systems, and outdated metallurgy contributed to ongoing vulnerability. The lack of real-time monitoring tools further hampered proactive intervention and accelerated damage progression in several cases.

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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.

References

- [1] Samimi, A. Bozorgian, A. Samimi, M. (2022), [An Analysis of Risk Management in Financial Markets and Its Effects](#), *Journal of Engineering in Industrial Research* 3 (1), 1-7, 2022
- [2] Alavi, A., & Mohammadi, M. (2020). [Effects of temperature on sulfidation in refinery furnaces](#). *Journal of Materials Engineering and Performance*, 29(5), 2781-2789.
- [3] Chen, L., & Zhou, M. (2021). [Mechanisms of chloride stress corrosion cracking in refinery stainless steels](#). *Corrosion Reviews*, 39(1), 57-68.
- [4] Das, P., & Roy, A. (2019). [Corrosion management practices in heavy oil refinery units](#). *Journal of Loss Prevention in the Process Industries*, 60, 104-113.
- [5] Fernandez, P., & Lopez, A. (2019). [Ultrasonic inspection of refinery furnace tubes for corrosion evaluation](#). *NDT & E International*, 106, 102137.
- [6] Gao, Y., & Liu, J. (2022). [Advances in corrosion-resistant coatings for refinery applications](#). *Surface and Coatings Technology*, 432, 128053.
- [7] Hassan, M., & Ali, F. (2021). [Statistical evaluation of corrosion rates in refinery units](#). *Corrosion Science*, 181, 109220.
- [8] Kumar, V., & Singh, R. (2020). [Wear-corrosion behavior of alloys in refinery environments](#). *Wear*, 460-461, 203471.
- [9] Samimi, A. (2024), [Risk Management in EPC Projects](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 3 (5), 185-195
- [10] Sadr, M. B. (2025). [Analysis of Spatial Criteria of Industries in the Village Based on Environmental Standards](#). *Journal of Chemical Engineering and Energy Materials*, 1(1), 1-8. doi: 10.22034/jceem.2025.220371
- [11] Samimi, A. (2021), [The Need for Risk Assessment in Occupational Health](#), *Journal of Engineering in Industrial Research*, 2 (2), 71-76
- [12] Navaei, O. [Personalized Medicine: Tailoring Treatment Plans Based on Genetic Profile](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2025, 4 (2), 129-151
- [14] Samimi, A. (2020), [Investigation the Impact of Risk Management and Audit Committee on Industrial Companies](#), *Journal of Exploratory Studies in Law and Management*, 7 (3), 132-137
- [15] Imanzadeh, M. (2025), [Development of Solid State Electrolytes for Next Generation Lithium-Ion Batteries](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 4 (1), 32-47
- [16] Samimi, A. (2021), [The Need for Risk Assessment in Occupational Health](#), *Journal of Engineering in Industrial Research*, 2 (2), 71-76
- [17] Ahmadpour, A. and Jalali, M. (2023). [Introduction of Consumable Primers in Consumable Tires of Petrochemical Complexes in Hard Rubber](#)

Types. *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2(5), 45-56.

[18] Gandomi, MJ. (2025), [Use of New Technologies for Enhanced CO2 Reduction Reactions](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 4 (1), 15-31

[19] Sabzehali, S. (2025), [Nanomaterials in Drug Delivery Systems: Challenges and Perspectives](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 4 (1), 48-62

[20] Kiamansouri, M. (2025), [Integration of Renewable Energy Sources in Oil and Gas Operations a Sustainable Future](#), *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 4 (1), 63-87

[21] Sapaev, I., Esanmurodova, N., Akhmatovna, A. M., Anvarjon, K., Khatamov, A., Asliddin, S. and Shukrillayevna, A. Z. (2025). [A Mini-Review on the Studies Done on the Acidification of Carbonate Rock Matrix](#). *Chemical Methodologies*, 9(6), 448-460.

[22] Ahmadpour, A. and Jalali, M. (2023). [Introduction of Consumable Primers in Consumable Tires of Petrochemical Complexes in Hard Rubber Types](#). *Eurasian Journal of Chemical, Medicinal and Petroleum Research*, 2(5), 45-56.

[23] Iorhuna, F., Ayuba, M. Abdullahi and Muhammad, A. Shehu (2023). [Computational Studies on the Corrosion Inhibition of Mild Steel Using Pyrimidine Derivatives](#). *Advanced Journal of Chemistry, Section B: Natural Products and Medical Chemistry*, 5(3), 244-260.

[24] Muhammad, A. A., Nyijime, T. A., Minjibir, S. A., Shehu, N. U. and Iorhuna, F. (2023). [Exploring the Inhibition Potential of Carbamodithionic acid on Fe \(111\) Surface: A Theoretical Study](#). *Journal of Engineering in Industrial Research*, 4(4), 201-210.

[25] A Samimi, S Zarinabadi, M Setoudeh, A Safavian, [Review Applications to Prevent Corrosion Reducing Gas Pipe Line](#), *International Journal of Basic and Applied science*, Indonesia, 2012, 423-428

[26] Ramezani, A., Shafiei, S., & Jafari, M. (2022). [Catalyst compaction and cake formation in fixed-bed reactors](#). *Chemical Engineering Journal*, 429, 132354.

[27] A Samimi, A Bozorgian, M Samimi, [An Analysis of Risk Management in Financial Markets and Its Effects](#), *Journal of Engineering in Industrial Research*, 2022, 3 (1), 1-7

[28] Hassanpour, A., Mohammadi, F., & Rezaei, M. (2023). [Role of temperature gradients on catalyst support weakening](#). *Applied Catalysis B: Environmental*, 320, 122312.

[29] Kim, D., & Han, J. (2023). [Hydrotreating catalyst lifetime modeling under dynamic operation](#). *Industrial & Engineering Chemistry Research*, 62(12), 4567-4578.

[30] Soltani, M., & Moradi, S. (2023). [Structural breakdown of Ni-Mo/Al₂O₃ catalysts at elevated temperatures](#). *Journal of Catalysis*, 415, 88-97.

[31] Zhang, H., Liu, B., & Yuan, T. (2023). [Experimental study on pressure drop due to catalyst deformation](#). *Journal of Petroleum Science and Engineering*, 226, 109847.

[32] A Samimi, S Zarinabadi, [The Comparison of Increasing Method for Petroleum Pits Output \(Fluids Dynamic\)](#), *International Journal of Basic and Applied science*, 2012, Indonesia, 435-439

[33] Mahdiraji, E. A.; Zarini, M. K. (2025), [Application of Distributed Algorithm in a Microgrid for Optimal Energy Management and Rapid Convergence](#). *Qjoest*, 6(1), 55-70.

[34] Mahdiraji, E. A.; Amiri, M. S. Shariatmadar, S. M. (2021), [Analysis of Lightning Strikes on the Transmission Line by Considering the Frequency-Dependent Model](#). *Qjoest*, 2(6), 12-36.

[35] Amouzad Mahdiraji, E., Shariatmadar, S. (2019), [A New Method for Simplification and Reduction of State Estimation's Computational Complexity in Stability Analysis of Power Systems](#). *International Journal of Smart Electrical Engineering*, 08(02): 51-58.

[36] Amouzad Mahdiraji, E., Shariatmadar, S. (2019), [Improving the Transient Stability of Power Systems Using STATCOM and Controlling it by Honey Bee Mating Optimization Algorithm](#). *International Journal of Smart Electrical Engineering*, 08(03): 99-104.

[37] Mahdiraji, E. A.; Amiri, M. S.; Shariatmadar, S. M. (2021), [Voltage Load Shedding Considering Voltage Sensitivity and Reactive Power](#). *Qjoest*, 2021, 2(6), 55-72.

[38] Khodadadi Zarini, M. Mahdiraji, EA. (2024), [Review of Energy Management in Micro Grid in Power Engineering](#). *J. Eng. Ind. Res*, 5 (2): 90-99.

[39] Mahdiraji, E. A. (2022), [Optimal Purchase and Sale of Energy in Electricity Markets Due to Various Uncertainties in Microgrid](#). *Qjoest*, 3(1), 29-39.

[40] Mahdiraji, EA. (2024), [Effects of Fourier Transform and Modal Theory in Electrotherapeutic Signals](#). *Eurasian Journal of Chemical, Medicinal and Petroleum Research*. 3(1):1-6.

[41] Mahdiraji, EA. Amiri, MS. (2021), [Adaptive Control of Network Frequency by Doubly-Fed Induction Generators Using a Data-Driven Method](#). *Eurasian. J. Sci. Technol*, 1(2), 75-91.

[42] Mahamedi, B., Zhu, J. G., & Hashemi, S. M. (2016). [A setting-free approach to detecting loss of excitation in synchronous generators](#). *IEEE Transactions on Power Delivery*, 31(5), 2270-2278.