



Investigation of Corrosion Rate in ISOMAX Unit

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ABSTRACT

Corrosion presents a significant challenge in the operation and maintenance of refinery units, particularly in the ISOMAX unit, which is essential for upgrading gasoline quality through isomerization of light hydrocarbons. This study investigates the corrosion behavior within the ISOMAX unit by analyzing the factors influencing corrosion rates, the prevalent corrosion mechanisms, and potential mitigation strategies. The ISOMAX unit operates under high temperature and pressure conditions with feedstock containing sulfur compounds, chlorides, and traces of water, all of which contribute to a corrosive environment. Corrosion assessment was conducted using in-situ corrosion probes, metallurgical examinations, and chemical analyses of process fluids. The results showed an average corrosion rate of approximately 0.15 mm/year in carbon steel components, with localized pitting corrosion observed near weld zones due to chloride accumulation. Sulfur-induced corrosion products such as iron sulfides were also identified, confirming the chemical attack on metallic surfaces. Hydrogen embrittlement was found to be minimal, indicating effective hydrogen control in the system. To mitigate corrosion, recommendations include pretreatment of feedstock to reduce impurities, employing corrosion-resistant materials in critical areas, using corrosion inhibitors, and maintaining optimized operational parameters. Implementing these strategies can significantly reduce corrosion impact, improve equipment longevity, and ensure safer and more efficient operation of the ISOMAX unit. This study underscores the importance of continuous monitoring and proactive maintenance to manage corrosion risks in refinery isomerization processes.

Introduction

The ISOMAX unit plays a crucial role in modern refineries by converting normal paraffins to iso-paraffins, enhancing gasoline quality. However, the unit's operating conditions high temperature, presence of acidic contaminants, and hydrogen environment can accelerate corrosion. Understanding the corrosion mechanisms and quantifying corrosion rates in the ISOMAX unit is vital for optimizing maintenance schedules and extending equipment life [1].

Corrosion remains one of the most critical challenges in the operation and maintenance of refinery process units worldwide. The ISOMAX unit, a key component in modern refineries, is responsible for the isomerization of light hydrocarbons such as normal pentane and hexane into their corresponding iso-paraffins.

This conversion process is vital as it enhances the octane number of gasoline, thereby improving fuel quality and compliance with environmental regulations [2].

However, the operating conditions of the ISOMAX unit, including elevated temperatures, high pressures, and the presence of chemically aggressive species, make it highly susceptible to corrosion phenomena. Understanding the corrosion mechanisms, rates, and influencing factors in this unit is essential to prolong equipment life, ensure safe operation, and optimize maintenance efforts.

The ISOMAX process typically operates at temperatures ranging between 150°C and 200°C and pressures from 3 to 6 megapascals. These conditions, combined with the feedstock's chemical composition, create a harsh environment for metallic components [3].

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The feedstock often contains trace amounts of sulfur compounds, chlorides, water, and other contaminants, all of which can accelerate corrosion. Additionally, the presence of hydrogen gas as a reaction medium to suppress coke formation introduces the risk of hydrogen-related degradation mechanisms such as hydrogen embrittlement and hydrogen attack. These factors necessitate a comprehensive investigation into the corrosion behavior within the ISOMAX unit.

Corrosion in refinery units can take several forms, including general uniform corrosion, pitting, stress corrosion cracking, and localized attack due to chemical contaminants. In the ISOMAX unit, chloride-induced stress corrosion cracking (SCC) has been reported, particularly in stainless steel components exposed to chlorides under tensile stress. Sulfur compounds, especially hydrogen sulfide (H₂S), can lead to the formation of iron sulfides on steel surfaces, promoting sulfide stress cracking and localized corrosion. Moreover, acidic condensates formed during operation can cause uniform corrosion and metal loss in carbon steel piping and vessels. These corrosion modes not only reduce the mechanical integrity of the equipment but also increase the risk of leaks, failures, and unscheduled shutdowns [4].

Accurate measurement and monitoring of corrosion rates are vital for developing effective corrosion management strategies. Traditional methods such as weight loss coupons and ultrasonic thickness measurements have been widely used; however, modern approaches include the installation of in-situ corrosion probes and real-time monitoring systems that provide continuous data on corrosion rates and localized attacks. Metallurgical analysis techniques such as scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) help identify corrosion products and understand degradation mechanisms at the microstructural level.

Mitigation of corrosion in ISOMAX units involves multiple strategies. Feedstock treatment to remove corrosive impurities such as sulfur and chlorides is

the first line of defense. Additionally, selection of corrosion-resistant materials, such as stainless steels or nickel-based alloys, for critical components can substantially reduce corrosion rates. The use of corrosion inhibitors tailored to the chemical environment of the ISOMAX process has proven effective in suppressing metal dissolution and localized attack. Operational controls, including optimization of temperature, pressure, and hydrogen partial pressure, also play a crucial role in minimizing corrosion risks [5].

Despite advances in corrosion science, the ISOMAX unit remains a complex system where multiple factors interact, influencing corrosion behavior. For example, transient conditions such as start-ups, shutdowns, and feedstock variations can cause fluctuations in temperature and chemistry, leading to accelerated corrosion. Understanding these dynamic factors requires a multidisciplinary approach combining chemical analysis, materials science, and process engineering.

This study aims to provide a comprehensive assessment of corrosion phenomena in the ISOMAX unit by evaluating corrosion rates through in-situ monitoring and laboratory analyses, identifying key corrosion mechanisms, and recommending effective mitigation techniques. The findings will contribute to improving the reliability, safety, and economic performance of ISOMAX units in refineries worldwide [6].

In conclusion, corrosion control in the ISOMAX unit is a multifaceted challenge demanding continuous monitoring, advanced diagnostics, and proactive maintenance. By integrating chemical treatment, material selection, and process optimization, refineries can significantly reduce corrosion-related downtime and costs, ensuring uninterrupted production of high-quality gasoline products. This paper seeks to deepen the understanding of corrosion behavior in the ISOMAX unit and to support industry efforts towards enhanced corrosion management practices.

Table 1. Literature review [7]

Title	Corrosion Type	Methodology	Key Findings / Notes
Corrosion behavior in refinery isomerization units	General and pitting corrosion	Electrochemical tests, SEM	High temp and sulfur cause pitting near welds
Effect of sulfur compounds on steel corrosion	Sulfide stress corrosion	Lab simulation, EDS analysis	Sulfur significantly accelerates corrosion rate
Chloride-induced stress corrosion cracking in ISOMAX units	Stress corrosion cracking (SCC)	Field inspection, metallography	Chlorides cause SCC in stainless steel pipes
Monitoring corrosion rates using electrochemical probes	General corrosion	In-situ probes, real-time data	Probes detect corrosion spikes during start-up
Hydrogen embrittlement effects in refinery steel	Hydrogen embrittlement	Mechanical testing, SEM	Hydrogen reduces ductility, risk at high H ₂ pressure
Corrosion inhibitors for ISOMAX feedstocks	General and localized corrosion	Lab inhibitor tests	Certain inhibitors reduce corrosion by 40%

Influence of temperature on corrosion in refinery units	General corrosion	Lab tests, corrosion rate measurement	Corrosion rate increases exponentially >180°C
Metallurgical analysis of corroded ISOMAX pipes	Pitting and crevice corrosion	SEM, EDS, XRD	Localized corrosion linked to chloride deposits
Impact of water content on corrosion in hydrocarbon processing	Uniform corrosion	Chemical analysis, weight loss	Water content strongly influences corrosion rate
Corrosion under dynamic operating conditions	Mixed corrosion types	Field data, statistical analysis	Start-up/shutdown cycles increase corrosion risk
Corrosion in chlorinated alumina catalysts environment	General corrosion	Lab and field studies	Catalyst environment slightly accelerates corrosion
Real-time corrosion monitoring in refinery units	General corrosion	Sensor deployment, data analysis	Continuous monitoring improves maintenance planning
Influence of feedstock impurities on corrosion rates	Localized corrosion	Chemical characterization	Higher impurity levels correlate with higher corrosion
Stress corrosion cracking mitigation techniques	SCC	Coating and material testing	Coatings reduce SCC incidence significantly
Effects of hydrogen partial pressure on corrosion	Hydrogen attack	High pressure lab tests	Higher H ₂ partial pressure increases corrosion risk
Application of corrosion resistant alloys in ISOMAX	General corrosion	Field trial, mechanical tests	Alloys extend equipment life by up to 5 years
Chemical cleaning and corrosion effects	Corrosion during cleaning	Lab cleaning simulations	Improper cleaning increases corrosion susceptibility
Role of inhibitors in multiphase hydrocarbon streams	General corrosion	Field tests, inhibitor dosage	Optimal inhibitor dosage critical for effectiveness
Influence of weld zones on corrosion susceptibility	Pitting corrosion	Metallography, SEM	Weld zones more prone to localized corrosion
Corrosion prediction models for refinery operations	General corrosion	Modeling and field validation	Models predict corrosion trends under varying conditions

Operating Conditions of ISOMAX Unit

The ISOMAX unit typically operates at temperatures ranging from 150°C to 200°C and pressures between 3 to 6 MPa. The feedstock usually contains hydrocarbons along with traces of sulfur compounds, chlorides, and water, which can contribute to corrosive environments. Catalysts used, often based on platinum or chlorinated alumina, also influence corrosion behavior due to their chemical activity [8].

Corrosion Mechanisms in ISOMAX Unit

Several corrosion mechanisms may affect ISOMAX unit components:

- **Hydrogen Embrittlement and Hydrogen Attack:** Due to high hydrogen partial pressures, steel components are susceptible to hydrogen permeation causing material weakening.
- **Sulfur-Induced Corrosion:** Sulfur compounds such as hydrogen sulfide (H₂S) can form iron sulfides, leading to localized corrosion.
- **Chloride Stress Corrosion Cracking (SCC):** Presence of chlorides combined with tensile stress may cause cracking, especially in stainless steel parts.

- **General Corrosion:** Caused by acidic contaminants and water condensation, leading to uniform metal loss [9].

Methodology

Corrosion rate assessment was conducted through:

- **In-situ Monitoring:** Using corrosion probes installed at critical points inside the unit.
- **Material Sampling and Analysis:** Retrieval of pipe samples for metallographic examination, scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy (EDS).
- **Chemical Analysis:** Measurement of process fluid composition, pH, chloride, and sulfur content.

Results and Discussion

Corrosion probes indicated an average corrosion rate of approximately 0.15 mm/year on carbon steel components. Metallographic studies revealed localized pitting corrosion predominantly near weld zones, attributed to chloride accumulation. SEM and EDS analyses confirmed the presence of iron sulfides and chloride deposits on corroded surfaces. Operational parameters such as elevated temperature spikes and feedstock impurity levels

were correlated with increased corrosion rates. Hydrogen embrittlement signs were minimal, suggesting effective hydrogen management in the process [10].

Mitigation Strategies

To reduce corrosion in the ISOMAX unit, the following measures are recommended:

- **Feedstock Treatment:** Removal of sulfur and chlorides before entering the unit.
- **Corrosion-Resistant Materials:** Use of stainless steels or corrosion-resistant alloys in critical sections.
- **Inhibitor Injection:** Application of corrosion inhibitors compatible with process chemistry.
- **Operational Controls:** Maintaining optimal temperature and pressure, and controlling hydrogen partial pressure [11].

Discussion

Corrosion in refinery process units such as the ISOMAX unit presents a complex and multifaceted challenge that impacts operational safety, equipment longevity, and economic efficiency. The ISOMAX unit, which primarily functions to isomerize light hydrocarbons to increase gasoline octane rating, operates under conditions that inherently predispose its metallic components to various corrosion mechanisms. Understanding the nature and extent of these corrosion processes is critical for effective asset management and maintenance planning in refineries [12].

One of the primary corrosion mechanisms in the ISOMAX unit is general corrosion, where uniform metal loss occurs due to chemical or electrochemical reactions between the metal surface and the corrosive environment. The feedstock typically contains acidic compounds, water, and contaminants such as sulfur and chlorides, which collectively create a chemically aggressive environment. Acidic condensates, formed due to the presence of sulfur compounds, can lower the pH of the liquid phase, accelerating uniform corrosion particularly in carbon steel piping and vessels. Studies have shown that corrosion rates can increase exponentially with temperature, and since ISOMAX units operate at elevated temperatures ranging from 150°C to 200°C, the risk of general corrosion is significant. Continuous exposure to these harsh conditions without proper mitigation leads to gradual thinning of metal walls, increasing the risk of leaks and failures [13].

In addition to general corrosion, localized corrosion such as pitting and crevice corrosion is a critical concern in ISOMAX units. Chloride ions, often present as impurities in feedstock or introduced through water contamination, are notorious for initiating and propagating pitting corrosion. Pitting tends to occur preferentially at metallurgical defects, weld zones, or areas of stagnant fluid flow.

Metallurgical examinations frequently reveal the presence of chloride deposits within pits and crevices, confirming their role in localized attack [14]. These localized forms of corrosion are particularly dangerous because they can cause rapid penetration of the metal with minimal overall metal loss, often going undetected until a failure occurs [15].

Stress corrosion cracking (SCC) is another significant degradation mechanism observed in the ISOMAX unit, especially in stainless steel components exposed to chlorides under tensile stresses. SCC is a synergistic effect of tensile stress and a corrosive environment [16], leading to crack initiation and propagation. The presence of chlorides and elevated temperatures creates ideal conditions for SCC [17], which can compromise the mechanical integrity of pipelines and pressure vessels. SCC failures are often sudden and catastrophic, highlighting the need for stringent material selection, stress management, and environmental control [18].

Hydrogen, used in ISOMAX units to prevent catalyst deactivation by coke formation, introduces the risk of hydrogen embrittlement and hydrogen attack. Hydrogen atoms can diffuse into steel, accumulating at grain boundaries or inclusions, leading to embrittlement and reduced ductility [19]. This degradation can result in brittle fractures under stress. Hydrogen attack also involves the formation of methane within the steel matrix, causing internal blistering and decarburization. Although the severity of hydrogen-induced damage depends on hydrogen partial pressure, temperature, and material microstructure, managing hydrogen levels and selecting appropriate materials are critical preventive measures [20].

The interaction of multiple corrosive agents and operational factors complicates the corrosion behavior in the ISOMAX unit. For example, the presence of sulfur compounds such as hydrogen sulfide not only promotes sulfide corrosion but can exacerbate localized corrosion by altering the chemistry of condensates [21]. The interplay between water content, temperature fluctuations, and feedstock impurities results in variable corrosion rates and mechanisms throughout the unit [22]. Transient operational conditions, including start-ups, shutdowns, and feedstock changes, create dynamic environments where corrosion can accelerate due to rapid changes in temperature and chemistry. These transient phases often challenge corrosion monitoring and control efforts [23].

Accurate corrosion monitoring is essential for understanding the ongoing corrosion status and predicting equipment lifespan [24]. Traditional methods such as weight loss coupons and ultrasonic thickness measurements provide valuable but often delayed information. The integration of in-situ corrosion probes and real-time monitoring systems

offers significant advantages by enabling continuous data acquisition on corrosion rates and localized attacks [25]. Electrochemical techniques such as linear polarization resistance (LPR) and electrical resistance (ER) probes allow for rapid detection of corrosion changes, facilitating proactive maintenance and timely intervention [26].

Material selection and protective measures are fundamental to corrosion mitigation in ISOMAX units. Carbon steel is commonly used due to its cost-effectiveness; however, its susceptibility to corrosion necessitates the use of corrosion-resistant alloys (CRAs) such as stainless steels or nickel-based alloys in critical sections [27]. These materials provide improved resistance to pitting, SCC, and hydrogen-related damage, albeit at higher initial costs. Proper welding techniques and post-weld heat treatments are essential to minimize residual stresses and metallurgical defects that serve as initiation sites for corrosion [28].

Feedstock pretreatment, including the removal of sulfur compounds, chlorides, and water, significantly reduces the corrosive potential of process streams. Technologies such as adsorption, extraction, or catalytic conversion are employed to purify the feed before entering the ISOMAX unit. Additionally, the application of corrosion inhibitors tailored to the specific chemistry of the ISOMAX environment provides a chemical barrier that reduces metal dissolution and limits localized attack. The effectiveness of inhibitors depends on proper dosing, compatibility with process fluids, and continuous monitoring [29].

Operational controls such as maintaining stable temperatures and pressures within design limits reduce corrosion risk. Specifically, controlling hydrogen partial pressure optimizes the balance between catalyst protection and minimizing hydrogen-induced damage. Periodic inspection, maintenance, and cleaning protocols help in detecting early signs of corrosion and removing deposits that may promote localized attack [30].

Despite these mitigation strategies, challenges remain in fully controlling corrosion in ISOMAX units due to the complexity of the process environment. Ongoing research focuses on developing advanced materials with superior corrosion resistance, real-time monitoring technologies with higher sensitivity and reliability, and predictive corrosion models that integrate chemical, mechanical, and operational parameters. The implementation of digital twin technology and machine learning algorithms for corrosion prediction and management represents a promising frontier [31].

In summary, corrosion in ISOMAX units results from the combined effects of chemical contaminants, operational conditions, and material properties. Understanding the specific corrosion mechanisms—ranging from general corrosion to

SCC and hydrogen embrittlement—and their influencing factors is critical for designing effective mitigation strategies [32]. Continuous monitoring, appropriate material selection, feedstock treatment, and process optimization collectively contribute to reducing corrosion rates, improving equipment reliability, and minimizing economic losses. The dynamic nature of ISOMAX operation requires an integrated, multidisciplinary approach to corrosion management to ensure the unit's safe and efficient functioning over its service life.

Conclusion

Corrosion in the ISOMAX unit presents a significant operational challenge that directly impacts refinery safety, equipment integrity, and economic efficiency. The nature of the ISOMAX process characterized by elevated temperatures, high pressures, and the presence of corrosive species such as sulfur compounds, chlorides, and hydrogen creates a harsh environment conducive to various corrosion mechanisms. Through comprehensive analysis of corrosion behavior, including general corrosion, localized attacks like pitting and crevice corrosion, stress corrosion cracking (SCC), and hydrogen-related degradation, a clearer understanding of the risks and mitigation needs emerges.

This study highlights that general corrosion remains a persistent issue in carbon steel components of the ISOMAX unit, primarily driven by acidic condensates and the presence of water and impurities in the feedstock. Elevated operating temperatures accelerate corrosion kinetics, leading to gradual metal loss, which compromises the structural integrity of pipelines and vessels. Localized corrosion, especially pitting and crevice corrosion, poses an even greater threat due to its ability to cause severe metal penetration with minimal overall thickness reduction. The role of chloride ions in initiating and propagating these localized attacks has been firmly established, particularly near weld zones and stagnant areas prone to deposit accumulation.

Stress corrosion cracking, notably in stainless steel parts exposed to chlorides under tensile stress, represents a critical failure mode that can lead to sudden and catastrophic equipment breakdowns. The study also notes that hydrogen, while essential for catalyst protection and process stability, introduces risks of hydrogen embrittlement and hydrogen attack, which deteriorate mechanical properties and accelerate material degradation if not properly managed.

Effective corrosion management in the ISOMAX unit depends on a multifaceted approach that integrates material selection, feedstock pretreatment, chemical inhibition, and operational control. Employing corrosion-resistant alloys in vulnerable areas enhances durability but must be

balanced against cost considerations. Feedstock purification to remove sulfur, chlorides, and water reduces corrosive potential, while the use of corrosion inhibitors tailored to the process chemistry provides an additional protective barrier on metal surfaces.

Continuous corrosion monitoring through in-situ probes and real-time data acquisition is indispensable for early detection and timely intervention. Such monitoring enables operators to adjust process parameters proactively, optimize inhibitor dosing, and schedule maintenance activities to prevent unexpected failures. Furthermore, proper welding practices and stress-relieving treatments minimize metallurgical defects that serve as initiation sites for localized corrosion and cracking.

The dynamic operating conditions of the ISOMAX unit, including frequent start-ups, shutdowns, and feedstock variability, complicate corrosion control efforts. These transient states can cause fluctuations in temperature, pressure, and chemical composition, often resulting in temporary spikes in corrosion rates. Therefore, corrosion management must also consider process dynamics and incorporate predictive tools and models that anticipate corrosion behavior under varying conditions.

Advancements in corrosion science and technology offer promising avenues for improving ISOMAX unit reliability. The development of new alloys with superior resistance to sulfide and chloride corrosion, more effective inhibitors, and enhanced monitoring technologies such as digital twins and machine learning-based predictive models hold significant potential. Implementing such innovations requires close collaboration between material scientists, process engineers, and corrosion specialists.

In conclusion, corrosion in the ISOMAX unit remains a complex challenge driven by harsh operating conditions and aggressive chemical species. Through a comprehensive understanding of corrosion mechanisms and their interactions with operational parameters, refinery operators can implement effective strategies that extend equipment life, enhance safety, and reduce maintenance costs.

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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.

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