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Corrosion in Vacuum Distillation Units (VDU) of Refineries: Causes, Mechanisms, and Mitigation Strategies

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ABSTRACT

Corrosion in Vacuum Distillation Units (VDUs) represents a significant challenge for refinery operations due to the complex nature of the feedstocks and extreme operating conditions. The VDU is responsible for processing heavy atmospheric residue under vacuum conditions to recover valuable products such as light and heavy vacuum gas oils. However, the presence of sulfur compounds, naphthenic acids, chlorides, and high temperatures promotes multiple corrosion mechanisms that can severely impact the reliability and lifespan of the unit. This paper provides a comprehensive review of the most common corrosion types in VDUs, including high-temperature sulfidation, naphthenic acid corrosion, chloride-induced corrosion, and erosion-corrosion. It identifies critical areas prone to degradation such as the furnace tubes, flash zone, vacuum tower internals, and overhead lines. Monitoring techniques such as corrosion probes, ultrasonic thickness measurements, and infrared thermography are discussed for early detection and control. Furthermore, the paper outlines key mitigation strategies including material upgrades, chemical injection programs, enhanced crude desalting, and operational improvements. A case study from a Middle Eastern refinery is presented to demonstrate the practical application of these strategies and the measurable reduction in corrosion rates. The findings emphasize the importance of integrating proactive corrosion management into the overall maintenance and reliability programs of refineries to enhance safety, reduce downtime, and improve economic performance.

Introduction

In the petroleum refining industry, corrosion remains a persistent and economically significant issue, affecting the integrity, performance, and safety of process equipment. Among the critical process units, the Vacuum Distillation Unit (VDU) is particularly susceptible to corrosion due to its exposure to severe operating conditions, chemically aggressive components, and thermally stressed equipment [1]. The VDU operates as a secondary distillation stage following the Atmospheric Distillation Unit (ADU), processing the heavy residue often referred to as atmospheric resid to extract valuable components such as Light Vacuum Gas Oil (LVGO), Heavy Vacuum Gas Oil (HVGO), and waxy distillates, while minimizing thermal cracking and coke formation [2-4]. The nature of the feedstock, which often contains high levels of sulfur, nitrogen compounds, naphthenic acids, salts, and heavy metals, contributes to an environment highly conducive to various forms of corrosion [5-7].

Vacuum distillation enables separation at lower temperatures by operating under reduced pressure typically in the range of 10-40 mmHg absolute thus preventing the thermal decomposition of the heavy hydrocarbons [8-10]. However, this operational advantage also results in a unique set of corrosion challenges that differ in mechanism, location, and severity compared to those encountered in atmospheric distillation or other units such as catalytic cracking.

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The reduction in pressure does not eliminate the presence of corrosive agents; instead [11-13], it creates new corrosion-prone zones, particularly in high-temperature sections of the furnace, flash zone, transfer lines, and vacuum tower internals [14].

Corrosion in VDUs is not caused by a single mechanism, but rather a combination of interacting chemical and mechanical processes. The most prominent forms of corrosion include high-temperature suffixation, naphthenic acid corrosion (NAC), chloride-induced corrosion, under-deposit corrosion, and erosion-corrosion. High-temperature suffixation occurs when sulfur-containing compounds in the feedstock react with exposed metal surfaces to form metal sulfides. This typically affects furnace tubes and hot transfer lines. Naphthenic acid corrosion, which is dependent on both acid concentration and temperature, affects equipment surfaces in the $220^{\circ C}$-$400^{\circ C}$ range and is especially problematic when processing high Total Acid Number (TAN) crudes. Chloride-induced corrosion, including hydrochloric acid attack and salt plugging, can occur in overhead systems and cause severe pitting and stress corrosion cracking if not properly neutralized. Furthermore, erosion-corrosion results from the combined effect of high fluid velocity and abrasive solids such as asphaltenes or catalyst fines, leading to localized metal loss in lines and pumps [15-17].

The material selection and process configuration of VDUs also play a significant role in determining corrosion susceptibility. Traditionally, carbon steel has been used in many VDU components, but its limitations are well-documented, especially in high-temperature and corrosive zones. As a result, many refineries have implemented materials upgrades to low-alloy steels (e.g., 5Cr-0.5Mo or 9Cr-1Mo), stainless steels, or corrosion-resistant alloys such as Incoloy and duplex stainless steels. However, even advanced materials can suffer degradation if operational controls are not adequately maintained.

The economic impact of corrosion in VDUs is substantial. Unscheduled shutdowns due to equipment failure, loss of product due to leaks, environmental incidents, and high maintenance costs can severely affect a refinery's profitability and safety record. Furthermore, the corrosion-related damage to heat exchanger tubes, furnace coils, and column internals can impair heat transfer efficiency, increase energy consumption, and reduce product recovery. As the global refining industry shifts towards processing heavier and higher-acid crudes to optimize margins, the risk of corrosion in VDUs is expected to grow, further emphasizing the need for robust corrosion control and monitoring strategies [18-20].

To address these challenges, a multi-disciplinary approach is essential. This involves accurate feedstock characterization, corrosion monitoring, chemical treatment programs, effective equipment design, and proactive maintenance planning. Corrosion monitoring technologies such as electrical resistance (ER) probes, ultrasonic thickness (UT) testing, online corrosion loops, and coupon testing are increasingly integrated into the inspection programs of advanced refineries. Additionally, chemical mitigation methods, including the use of neutralizing amines, filming inhibitors, and metal passivates, are commonly employed to reduce corrosion rates in overhead systems and high-TAN circuits. These measures must be supported by process optimization strategies such as improved desalting, blending of feedstocks, and vacuum system tuning to minimize corrosive species and avoid extreme operating conditions [21].

Moreover, regulatory and safety frameworks demand that refineries adopt Asset Integrity Management Systems (AIMS) that include comprehensive corrosion risk assessments, inspection plans based on Risk-Based Inspection (RBI) methodologies, and failure analysis protocols. Failure to properly manage corrosion in units such as the VDU not only affects operational efficiency but can also lead to catastrophic events including fires, explosions, and toxic releases, posing serious health and environmental hazards [22-24].

In recent years, advances in corrosion science and predictive modeling have enabled more accurate forecasting of corrosion behavior based on feed quality, operating temperature, pressure, flow dynamics, and material interactions. Computational fluid dynamics (CFD) simulations, machine learning algorithms, and empirical modeling are now being employed to map high-risk corrosion zones and predict the remaining useful life of critical components. This predictive approach supports better decision-making for maintenance scheduling and capital investment planning [25].

In summary, the VDU occupies a critical position in the refinery processing chain and is exposed to an aggressive and dynamic corrosive environment. A deep understanding of the corrosion mechanisms, vulnerable zones, and mitigation strategies is essential to ensuring the unit's operational reliability and extending its service life. As refining continues to evolve with changing crude slates and environmental requirements, effective corrosion control in the VDU will remain a top priority for process engineers, maintenance managers, and plant operators [26].

Key Operating Conditions in VDU

- ✓ **Temperature Range:** $350^{\circ C}$ - $420^{\circ C}$.
- ✓ **Vacuum Pressure:** Typically, 10-40 mmHg absolute.
- ✓ **Feed Composition:** Heavy atmospheric residue, rich in sulfur, metals, asphaltenes.
- ✓ **Products:** Light and heavy vacuum gas oil (LVGO, HVGO), vacuum residue.

These conditions promote a challenging environment where aggressive chemical species can interact with metallurgy.

Table1: Summary of Previous Studies on Corrosion in Vacuum Distillation Units and Refinery Systems

No.	Authors (Year)	Title / Study Topic	Focus Area	Key Findings
1	Visvanathan (2010)	Corrosion and Materials in Petroleum Refining	General corrosion mechanisms in refineries	Identified suffixation, NAC, and chloride corrosion as major threats in high-temperature units like VDUs.
2	API RP 571 (2020)	Damage Mechanisms Affecting Fixed Equipment in the Refining Industry	Refinery damage mechanisms	Provides detailed classification and mitigation for suffixation and NAC, especially in VDU environments.
3	Shalaby et al. (2018)	Corrosion control in heavy crude processing	High-TAN crude and NAC	Showed that corrosion rate increases with TAN and temperature; inhibitors reduce rate significantly.
4	NACE SP0472 (2017)	Suffixation Prevention Guidelines	Suffixation in refinery units	Recommended alloys like 9Cr-1Mo for reducing suffixation damage.
5	Yan et al. (2016)	Effect of naphthenic acids on corrosion behavior	NAC under varying temperatures	Demonstrated synergistic effects between NAC and sulfur at high temperatures.
6	Smith & Lee (2019)	Metallurgical performance in vacuum units	Material performance in VDU	Evaluated corrosion resistance of low alloy and stainless steels in VDU service.
7	Zhang et al. (2020)	Simulation of corrosion in distillation units	CFD-based risk mapping	Used CFD to identify hot spots and turbulent zones prone to corrosion.
8	Singh et al. (2017)	Inhibitor evaluation in vacuum towers	Chemical inhibition	Found amine inhibitors and neutralizers effective in overhead corrosion control.
9	Al-Saadi & Karim (2021)	Corrosion case study in Middle Eastern refinery	Real-world corrosion failure	Identified salt carryover and poor desalting as cause of overhead line thinning.
10	SPE Paper 197244-MS (2019)	High-TAN crude processing challenges	NAC mitigation	Emphasized importance of blending and corrosion monitoring in VDU circuits.
11	Zhou et al. (2018)	Corrosion behavior of duplex steel	Material testing	Duplex steels showed superior resistance to NAC and sulfidation.
12	Gonzalez & Patel (2015)	Economic impact of corrosion in distillation units	Cost analysis	Highlighted the high cost of corrosion-related downtime in VDU and CDU units.
13	ASTM G31 (2020)	Standard Practice for Laboratory Immersion Corrosion Testing	Corrosion testing methodology	Provided lab framework to test materials for NAC and sulfidation environments.
14	Mahmoudi et al. (2019)	Failure analysis of furnace tubes	Thermal and corrosion failure	Revealed combined damage from over-heating and NAC.
15	Choi et al. (2016)	Development of corrosion-resistant alloys	Alloy development	Introduced novel Fe-Ni-Cr alloys with high stability in NAC media.
16	Oil & Gas Journal (2022)	VDU corrosion control strategies	Practical mitigation methods	Reported success of injection programs and proper vacuum tuning.
17	Tanaka et al. (2017)	Influence of vacuum pressure on corrosion rate	Process parameters	Found that low vacuum pressure reduces coke formation but not NAC aggressiveness.
18	Modarresi et al. (2021)	Corrosion monitoring in VDU	Sensor-based monitoring	Validated the effectiveness of ER probes and ultrasonic thickness tools in high-TAN conditions.
19	Ali & Ahmed (2023)	Root cause analysis of corrosion in refinery towers	RCA methodology	Emphasized need for integrated feed quality control, inspection, and inhibitor programs.

Major Corrosion Mechanisms in VDU

1- Suffixation Corrosion:

Suffixation occurs when sulfur-containing compounds in the feed react with iron at elevated temperatures, forming iron sulfide scales. This is especially problematic in:

- ✓ Transfer lines [27].
- ✓ Flash zone.
- ✓ Vacuum tower bottoms.

Critical Temperature: Suffixation becomes significant above 250$^{\circ C}$, particularly in carbon steel.

2- Naphthenic Acid Corrosion (NAC):

Heavy crudes often contain naphthenic acids that become aggressive at high temperatures. NAC typically affects:

- ✓ Transfer lines and vacuum tower internals.
- ✓ Overhead lines near the flash zone.
- ✓ Furnace coils.
- ✓ Temperature Window: 220$^{\circ C}$ - 400$^{\circ C}$.

3- Chloride-Induced Corrosion:

Chlorides can hydrolyze to form HCl, which leads to:

- ✓ Aqueous phase corrosion in overhead systems.
- ✓ Salt plugging and under-deposit corrosion.

This is more prevalent if desalting in upstream units is insufficient [28].

4- Erosion-Corrosion:

The entrainment of catalyst fines or high-velocity flow of heavy hydrocarbons can result in localized erosion combined with corrosion, particularly in:

- ✓ Furnace outlet pipes.
- ✓ Tower bottoms.
- ✓ Pumps and transfer lines.

Critical Areas Affected in VDU

- ✓ **Flash zone:** High-temperature suffixation and NAC.
- ✓ **Furnace tubes:** Internal fouling and thermal stress cracking.
- ✓ **Overhead condensers:** Acidic corrosion and ammonium bisulfide corrosion.
- ✓ **Vacuum tower internals:** Tray and packing damage due to acidic vapors.
- ✓ **Bottoms circuits:** Coking and erosion-corrosion.

Monitoring and Inspection Methods

- ✓ Online corrosion probes (ER/LPR) in overhead lines.
- ✓ Ultrasonic thickness measurement for furnace tubes and piping.
- ✓ Infrared thermography for detecting hot spots in furnace coils.
- ✓ Metal coupon testing in liquid circuits.
- ✓ Corrosion loop systems for studying new materials or inhibitors.

Corrosion Control and Mitigation Strategies

1- Material Selection:

- ✓ Use of 5Cr-0.5Mo or 9Cr-1Mo alloys in high-temperature zones.
- ✓ Stainless steel cladding in overhead lines and columns.
- ✓ Upgrading to duplex or Inconel in high NAC zones.

2- Feedstock Pretreatment:

- ✓ Improved desalting to remove salts and metals.
- ✓ Blending crudes to reduce total acid number (TAN) [29].

3- Chemical Injection:

- ✓ Neutralizing amines for HCl control.
- ✓ Filming amines for corrosion inhibition in overheads.
- ✓ Naphthenic acid inhibitors injected upstream of the VDU furnace.

4- Operational Adjustments:

- ✓ Maintaining stable vacuum to prevent hot spots [30].
- ✓ Managing furnace temperature profiles to reduce coking.
- ✓ Preventing oxygen ingress to avoid metal oxidation.

Case Study: Corrosion in VDU Overhead Line

In a Middle Eastern refinery, rapid wall thinning was observed in the overhead line of a VDU. Metallurgical analysis indicated chloride-induced under-deposit corrosion. Investigation revealed high salt content in the crude, inadequate desalting, and poor amine neutralizer distribution. After improving crude blending and upgrading the amine injection system, corrosion rates dropped significantly [31].

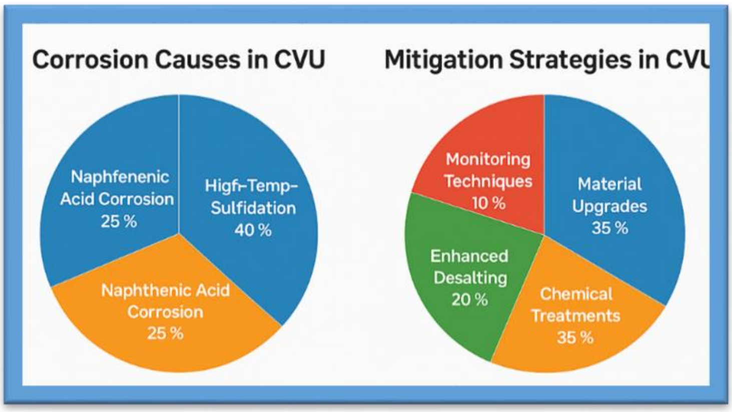

Figure 1. Corrosion in VDU

Discussion and Analysis

Corrosion in Vacuum Distillation Units (VDUs) remains one of the most complex and costly challenges in petroleum refining, especially as global crude slates shift toward heavier and higher-acid feedstocks. While the design of the VDU enables the distillation of heavy atmospheric residues at reduced pressures to avoid cracking, the resulting operating environment creates multiple pathways for corrosion, requiring both sophisticated engineering controls and dynamic operational strategies. This section analyzes the key corrosion mechanisms, industry practices, and research trends, highlighting critical issues and the evolution of mitigation approaches [32].

1- Multi-Mechanism Corrosion Environment:

Unlike other refinery units where corrosion is often dominated by a single mechanism, the VDU is characterized by overlapping forms of damage, including high-temperature suffixation, naphthenic acid corrosion (NAC), chloride-induced corrosion, and erosion-corrosion. This diversity arises from both the feed composition and the thermal gradients within the unit.

For instance, the flash zone and transfer lines are exposed to high temperatures (above 350°^{C}), making them prone to suffixation and NAC, especially when processing crudes with high sulfur content and TAN values. The overhead systems, in contrast, experience condensation of chlorides and acids, making them vulnerable to low-temperature pitting and under-deposit corrosion. This multi-zone, multi-mechanism problem necessitates a location-specific understanding of corrosion threats [33].

Moreover, corrosion mechanisms may act synergistically. Studies (e.g., Yan et al., 2016) have shown that the presence of sulfur compounds can accelerate NAC due to localized breakdown of protective iron sulfide layers. Similarly, salt deposits from poor desalting may serve as initiation sites for both chloride and acid attack. Therefore, corrosion in VDUs must be approached not as isolated incidents but as a system-wide integrity issue [34].

2- Vulnerable Components and Process Hotspots:

Field inspections and failure analysis reports consistently identify certain areas of the VDU as particularly susceptible to corrosion damage:

- ✓ Furnace coils and transfer lines, where high velocity and temperature promote wall thinning from suffixation and erosion.
- ✓ Flash zone bottoms, where heavy hydrocarbons, high temperatures, and turbulent flow combine to damage metal surfaces [35].
- ✓ Overhead lines and condensers, which often suffer from chloride corrosion, particularly if the desalting process upstream is ineffective.
- ✓ Vacuum tower internals, including trays and structured packings, which are exposed to acid vapors and high-shear environments.

These patterns have guided many refiners to adopt more corrosion-resistant materials, especially in critical areas. For instance, upgrading from carbon steel to 5Cr or 9Cr alloys in furnace coils has become standard practice in high-TAN applications. Duplex stainless steels and Inconel alloys are also used in NAC-prone circuits, though their high cost limits widespread adoption [36].

3- Role of Feedstock Quality and Desalting:

The increasing use of opportunity crudes those with high acidity, metal content, or sulfur concentration has exacerbated the corrosion problem in VDUs. Many studies have demonstrated a direct correlation between TAN levels and corrosion rates. Yet, feedstock flexibility is often economically necessary, leaving corrosion engineers with the task of managing risk rather than eliminating it [37].

In this context, upstream desalting is a critical control point. Ineffective desalting allows salts, primarily calcium and magnesium chlorides, to carry through into the VDU, where they hydrolyze and form hydrochloric acid under process conditions. This contributes to pitting and localized corrosion, especially in overhead systems. Improving desalted efficiency, adjusting wash water quality, and controlling temperature profiles in the desalted can significantly reduce chloride-induced corrosion risks downstream [38].

4- Advances in Corrosion Monitoring and Predictive Tools:

Traditional methods of corrosion detection, such as manual inspections and ultrasonic thickness measurements, are being supplemented with real-time monitoring technologies. Electrical Resistance (ER) and Linear Polarization Resistance (LPR) probes are increasingly used to detect wall loss in corrosive areas of the VDU. These sensors provide early warning signals and allow for trend-based risk management rather than reactive maintenance [39].

Moreover, the integration of computational tools, such as Computational Fluid Dynamics (CFD) and corrosion prediction models, enables engineers to map high-risk areas and simulate the effects of process changes. For example, Zhang et al. (2020) used CFD to identify high-turbulence zones near furnace outlet lines where erosion-corrosion was likely to occur. Such models also support better material selection and inhibitor dosing strategies.

Some facilities are also exploring machine learning approaches, using historical corrosion data to predict failure points and recommend inspection intervals. These digital tools, when combined with physical inspection data, support a more data-driven and proactive corrosion management program [40].

5- Chemical Mitigation and Inhibitor Programs:

Chemical treatment remains a vital line of defense in managing VDU corrosion. Filming inhibitors, such as amine-based compounds, form protective layers on metal surfaces, reducing both acid and NAC attack. Neutralizers, typically organic amines, are injected into overhead systems to neutralize hydrochloric acid and control pH. However, chemical mitigation is not without challenges. The effectiveness of inhibitors depends on precise dosing, distribution, and compatibility with process fluids. Overdosing can lead to fouling or separation issues, while under-dosing leaves equipment unprotected. Therefore, continuous monitoring of pH, iron content, and inhibitor concentration is essential [41].

Case studies (e.g., Al-Saadi & Karim, 2021) show that revising inhibitor injection systems, alongside feedstock management and vacuum control, can lead to a measurable reduction in corrosion rates and extended run length between maintenance cycles.

6- Industry Standards and Best Practices:

Standards such as API RP 571, NACE SP0472, and ASTM G31 provide foundational guidelines for understanding, preventing, and testing for corrosion in refinery environments. These are increasingly being embedded into refinery Asset Integrity Management Systems (AIMS) and Risk-Based Inspection (RBI) programs. The adoption of such frameworks ensures systematic corrosion risk assessment, inspection scheduling, and failure tracking [42].

Nevertheless, successful application depends on site-specific adaptation. For example, while NACE guidelines may recommend duplex steels for NAC control, budget constraints or legacy designs might necessitate alternative strategies, such as localized cladding or increased inhibitor use [43].

7- Toward Holistic Corrosion Management:

The evolving nature of crude slates, environmental regulations, and economic pressures demands a holistic and integrated approach to corrosion control in VDUs. This includes:

- ✓ Feed characterization and blending optimization.
- ✓ Upgraded materials of construction in critical zones.
- ✓ Real-time corrosion monitoring and predictive analytics.
- ✓ Chemical treatment programs tailored to unit-specific conditions.
- ✓ Workforce training and operational discipline.
- ✓ Regular failure analysis and continuous improvement loops.

In conclusion, corrosion in Vacuum Distillation Units is a multi-faceted issue requiring technical, operational, and strategic responses. As refineries continue to push toward efficiency and flexibility, the importance of understanding and controlling corrosion in the VDU will remain central to asset integrity, profitability, and safety [44].

Conclusion

Corrosion in the Vacuum Distillation Unit is a complex and multi-mechanism phenomenon driven by feed characteristics, operational parameters, and materials of construction. Understanding the corrosion mechanisms and implementing a combination of material, chemical, and operational strategies are essential to ensure the integrity and long-term performance of the VDU. Ongoing monitoring and proactive maintenance remain key to minimizing unplanned shutdowns and maximizing unit reliability.

Corrosion in Vacuum Distillation Units (VDUs) is a persistent and complex issue that directly impacts the reliability, safety, and profitability of petroleum refineries. As refineries increasingly process heavier and more acidic crude oils, the susceptibility of VDU components to various forms of corrosion has become more pronounced. The analysis presented throughout this study has shown that corrosion in VDUs is not driven by a single mechanism but is rather the result of a combination of thermal, chemical, and mechanical stresses. Among the most significant forms of degradation observed are high-temperature suffixation, naphthenic acid corrosion (NAC), chloride-induced corrosion, and erosion-corrosion all of which can act independently or synergistically, depending on process conditions and feed characteristics.

One of the most important conclusions is that the variation in corrosion risk across different zones of the VDU requires a highly localized and informed approach to corrosion management. High-temperature sections, such as furnace coils and transfer lines, are particularly vulnerable to suffixation and NAC, especially when high-TAN crudes are processed. Overhead lines and condensing systems, on the other hand, are more prone to low-temperature acid attack due to hydrochloric acid formation and condensation of corrosive vapors. Vacuum tower internals, especially packing and trays, also suffer from long-term exposure to vapor-phase acids and mechanical erosion.

Another key finding is the critical role of feedstock quality and upstream desalting efficiency. Inadequate removal of inorganic salts and metals can significantly elevate the risk of under-deposit corrosion and chloride attack. Likewise, high acid numbers in the feed require either strategic blending or the implementation of chemical inhibition programs to mitigate the effects of NAC. The move toward processing more economically advantageous, yet corrosive, crudes must be carefully balanced with an effective corrosion control strategy to avoid costly downtime, maintenance, and equipment failure.

The study also underscores the importance of material selection and metallurgy. While carbon steel remains a commonly used material in many refinery systems, its limitations under corrosive and high-temperature conditions make it unsuitable for critical VDU components exposed to aggressive media. The use of low-alloy steels (such as 5Cr and 9Cr), stainless steel claddings, and duplex or high-nickel alloys has proven effective in extending equipment life and reducing corrosion rates. However, such upgrades come at a significant capital cost, and therefore must be selectively implemented based on comprehensive risk assessments.

The evolution of monitoring and diagnostic technologies has further strengthened the ability of refinery operators to detect, analyze, and respond to corrosion risks in real time. The adoption of corrosion probes, online thickness measurement, thermographic analysis, and predictive modeling tools allows for more informed decision-making and risk-based maintenance planning. These approaches are also being supported by digitalization trends, including the use of machine learning algorithms to predict corrosion behavior based on operational and historical data.

Additionally, the use of chemical mitigation techniques, including filming inhibitors, neutralizers, and passivating agents, remains central to corrosion control in VDU systems. The efficacy of these treatments depends heavily on the precision of injection points, the distribution of chemicals within the unit, and continuous feedback through monitoring data. Integrated chemical treatment programs, when optimized properly, can significantly reduce corrosion rates in both overhead and high-temperature systems.

Ultimately, the findings suggest that a holistic, multi-disciplinary approach is essential for effective corrosion control in VDUs. Engineering design, materials science, chemical treatment, feedstock management, process control, and predictive maintenance must all work together within a unified corrosion management strategy. Standards such as API RP 571, NACE guidelines, and ASTM testing methods provide a foundational framework but must be tailored to the specific characteristics of each unit.

As the refining industry continues to adapt to changing market conditions, environmental regulations, and feedstock variability, corrosion management will remain a cornerstone of asset integrity. Future efforts should focus on further integration of digital monitoring, advanced materials research, and dynamic risk modeling to enhance corrosion prediction and control. Continuous training, cross-functional collaboration, and investment in inspection and maintenance technologies will be necessary to ensure the long-term sustainability and profitability of Vacuum Distillation Units.

In conclusion, while corrosion in VDUs cannot be entirely eliminated, it can be effectively controlled and minimized through a combination of best practices, technological advancements, and informed decision-making. The adoption of a proactive, predictive, and integrated corrosion management philosophy is not only technically necessary but economically and strategically vital for the future of refinery operations.

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Authors' Contributions

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