Titus Ndiele Amadi, 2026, 14:4
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Comparative Study of Atmospheric Corrosion of Carbon Steel in Gas-Flaring and Non-Gas Flaring Environments of the Niger Delta

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Abstract- This study presents a comparative assessment of atmospheric corrosion of carbon steel exposed in gas-flaring and non-gas flaring environments of the Niger Delta. The investigation examines corrosion mechanisms, and corrosion rates, and its implications for industrial infrastructure. Results indicate that carbon steel exposed in gas-flaring areas experiences substantially higher corrosion rates than steel exposed in non-gas flaring areas due to increased pollutant concentrations, acidic precipitation, elevated temperatures, and higher atmospheric conductivity. The study highlights the need for improved corrosion management strategies and stricter environmental controls in oil-producing regions.

Keywords— Atmospheric corrosion, Carbon steel, Gas flaring, Niger Delta.

I. INTRODUCTION

Atmospheric corrosion is a major challenge affecting the durability and service life of carbon steel structures exposed to outdoor environments. In the Niger Delta region of Nigeria, extensive gas-flaring activities associated with petroleum exploration have significantly altered atmospheric conditions through the release of sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO_2), particulate matter, and heat (Opurum et al., 2025; Solomon et al., 2019). These pollutants contribute to acid rain formation and increase atmospheric aggressiveness, thereby accelerating corrosion processes (Kiani & Olisa, 2021;).

Atmospheric corrosion is an electrochemical process occurring when a thin electrolyte film forms on metal surfaces due to moisture condensation, rainfall, or high relative humidity. The presence of pollutants such as sulfur compounds, chlorides, and nitrogen oxides significantly accelerates the corrosion process (Obia et al., 2011; Nkwocha & Pat-Mbano, 2010).

Corrosion is the gradual deterioration of materials due to chemical or electrochemical interactions with their environment (Amadi & Chidi, 2026; Obot & Anyakwo, 2017). Carbon steel, owing to its low cost, excellent mechanical properties, and wide availability, is extensively used in pipelines, storage tanks, offshore platforms, structural supports, and processing facilities within the oil and gas industry (Amadi & Erewari 2026; Ekpoh & Obia, 2010). However, its susceptibility to atmospheric corrosion poses serious operational and economic challenges. Several researchers have reported strong correlations between industrial emissions and increased atmospheric corrosion rates. Sulfur dioxide dissolves in atmospheric moisture to form sulfurous and sulfuric acids, lowering the pH of surface electrolyte films and enhancing metal dissolution (Adeoye, 2021). Nitrogen oxides similarly contribute to acid rain formation and environmental degradation (Nwaogu & Onyeze, 2020; Arroyave & Moroillo, 1995).

The Niger Delta region of Nigeria hosts extensive oil and gas exploration and production activities. One of the most environmentally significant practices in the region is gas flaring, which involves the combustion of associated natural gas released during crude oil extraction. Despite regulatory efforts to reduce gas flaring, numerous flare stacks continue to operate, releasing substantial quantities

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of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter, and other combustion by-products into the atmosphere (Uyigue & Enujekwu, 2017; Ologunorisa, 2001).

The Niger Delta's unique combination of coastal influence, high humidity, elevated temperatures, and industrial emissions create conditions favorable for severe atmospheric corrosion. Studies have shown that corrosion rates near oil and gas facilities often exceed those observed in rural environments due to pollutant deposition and prolonged wetness periods (Obot & Anyakwo, 2017; James et al., 2018). Gas-flaring operations intensify these effects by introducing acidic gases and particulate contaminants into the atmosphere (Solomon et al., 2019; Dung et al., 2008).

Gas flaring releases large quantities of sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter ($PM_{2.5}$ and PM_{10}), black carbon (Kingsley et al., 2024). These pollutants increase atmospheric acidity and promote acid rain formation. Studies have shown that gas-flaring communities in the Niger Delta experience elevated concentrations of sulfates, nitrates, and dissolved solids in rainwater and soils (Ubani & Onyejekwe, 2013). These acids reduce the pH of rainwater and significantly increase the corrosion rate of exposed carbon steel (Cole et al., 2003; Arroyave & Moroillo, 1995).

Atmospheric corrosion occurs when a thin electrolyte film forms on the metal surface, enabling electrochemical reactions that result in material deterioration (Ekpoh & Obia, 2010; John & Misel, 2018). In gas-flaring regions, pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) dissolve in atmospheric moisture to form sulfuric and nitric acids, increasing the corrosivity of rainwater and accelerating steel degradation. Atmospheric corrosion of carbon steel is fundamentally an electrochemical process involving anodic and cathodic reactions (Obia et al., 2011; Ekpoh & Obia, 2010).

Anodic Reaction

$$Fe \rightarrow Fe^{2+} + 2e-$$

Cathodic Reaction

$$O_2 + 2H_2O + 4e- \rightarrow 4OH-$$

Formation of Rust

$$2\ Fe^{2+} + 4OH- \rightarrow 2Fe(OH)_2$$

Further oxidation produces hydrated ferric oxide (rust):

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$$

$$4Fe(OH)_3 \rightarrow 2Fe_2O_3 \cdot xH_2O$$

The corrosion process is accelerated by high relative humidity, acidic pollutants, elevated temperatures, salt deposition, and industrial emissions, among others (Ologunorisa, 2001).

This study compares the atmospheric corrosion behavior of carbon steel exposed in gas-flaring and non-gas flaring areas of the Niger Delta. Although several investigations have addressed environmental impacts of gas flaring, comparative assessments of atmospheric corrosion of carbon steel in gas-flaring and non-gas flaring environments remain relatively limited. This study contributes to closing that knowledge gap. Hence, the findings provide valuable insights into material degradation mechanisms and support the development of effective corrosion management strategies.

II. MATERIALS AND METHODS

1. Study Area

The investigation was conducted in selected gas-flaring and non-gas flaring communities within the Niger Delta region. The gas-flaring locations were characterized by active flare stacks within proximity, elevated industrial emissions, high ambient temperatures, frequent exposure to combustion products while the non-gas flaring locations were selected based on absence of nearby flare stacks, similar climatic conditions, comparable coastal influence, reduced industrial pollution, among other factors. The experiment was conducted in two different communities – Umudioga and Apani-

Umuanyamele Communities. Umudioga is in Emuoha Local Government Area of Rivers State. It is an oil-bearing community where gas flaring takes place. The geographical coordinates of the community are Latitude 5.171180 N, and Longitude 6.797380 E, while Apani-Umuanyamele community is in Ikwerre Local Government Area of Rivers State. It is also an oil-bearing community, but there is no gas flaring activity taking place there, hence, serves as the control site for this study. The geographical coordinates of Apani are 5.20710 N, and Longitude 6.91300 E. Both communities are in the Niger delta. Figure 1 below is the Google map showing the location of the two communities.

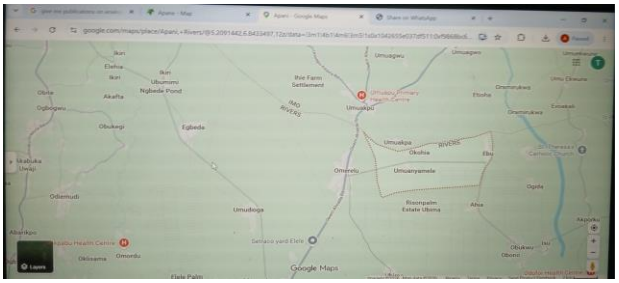

Figure 1: Google Map showing the study areas

2 Materials

The following materials were used for the study carbon steel coupons, analytical balance, vernier caliper, desiccators, emery papers, acetone, distilled water, wooden table, measuring tape, bowl.

3. Method

Experimental Procedure

The carbon steel coupons used for the study were obtained from a known company in Port Harcourt, Rivers State – Nigeria and prepared in accordance with standard procedure (Amadi & Wami, 2009). Steel coupons were cut into uniform dimensions (100 mm × 100 mm × 2mm), polished using abrasive papers, degreased with acetone, rinsed with distilled water, and air-dried. Initial weights were determined using a digital weighing balance. A total of 42 corrosion coupons were prepared and used for the study. Six (6) coupons were exposed at multiple distances away from the flare stacks 100 m, 500 m, 1 km, 1.5km, 2km & 2.5km in the direction of wind flow. At the non-gas flaring community (Apani-Umuanyamele), Six (6) coupons were also exposed to the atmosphere to serve as control. It should be noted that the coupons were placed on wooden material at about 1metre above the ground level. At regular intervals of 60 days, a coupon was retrieved, cleaned, reweighed, and the weight-loss determined. This continued throughout the period of the experiment, which lasted for a total of 360 days.

Corrosion Rate Determination

Weight loss method

The weight-loss and its subsequent corrosion rate were determined as shown below (Amadi & Wami, 2023; Onwugbuta, & John, 2020).

$$W = W_i - W_f \quad (1)$$

where

$W_i = Initial\ weight$

$W_f = final\ weight$

Corrosion Rate

$$CR = \frac{8.76\ x\ 10^4\ x\ W}{\rho\ x\ A\ x\ T} \quad (2)$$

Where:

CR = Corrosion Rate (mm/year)

W = Weight loss (mg)

ρ = Density of steel (g/cm^3)

A = Surface area (cm^2)

T = Exposure time (hours)

III. RESULTS AND DISCUSSION

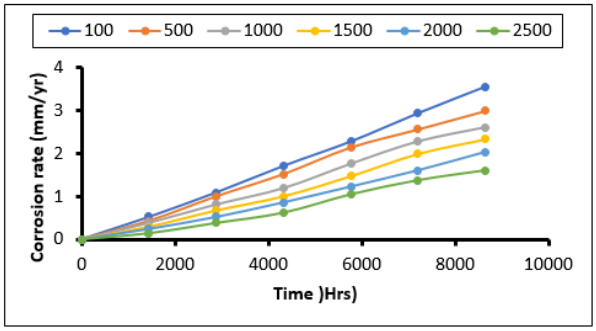

Figure 2: Corrosion rate versus Time at different Points in a Gas Flaring Environment

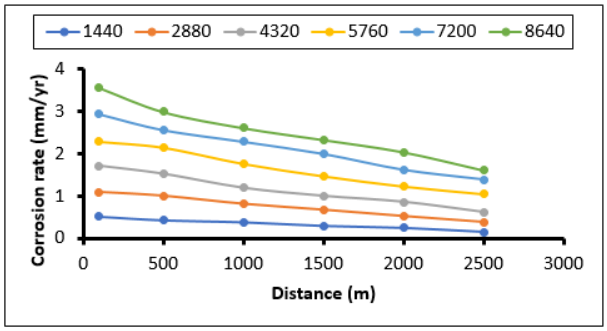

Figure 3: Corrosion rate versus Distance at different Time in a Gas Flaring Environment

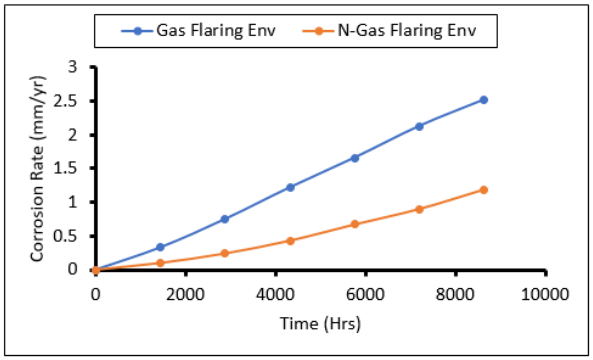

Figure 4: Corrosion Rate in Gas Flaring and Non-Gas Flaring Environments

Figure 2 shows the corrosion rate of carbon steel with time. It is observed that corrosion increased as time increased in each of the points or distances away from the stack where the carbon steel coupons were exposed. Metals such as carbon steel has less protective and porous films thereby making the corrosion rate to flatten out and become diffusion-controlled (Amadi et al., 2011; Bai et al., 2018). The gas-flaring environment exhibited lower rainwater pH and higher pollutant levels, creating more aggressive corrosion conditions with time. The acidity of the environment does not allow the formation of protective layers, hence, causing a steady, continuous corrosion rate or accelerated pitting (Ekpoh & Obia, 2010).

Figure 3 shows the corrosion rate of carbon steel at different points (100m, 500m, 1,000m, 1,500m, 2,000m, and 2,500m) away from the gas flaring point. The results revealed that corrosion rate decreased with increase in distance away from the gas stack. Corrosion rate occurred most at 100m distance, followed by 500m distance. This is made possible due to excessive heat emanating from the gas stack. Research has shown that high temperature in an environment can drastically alter the mechanical, electrical, and the physical properties of engineering materials situated in such environment (Konovalova, 2020). In addition, studies have also shown that heat increases the kinetic energy of the metal particles, thereby driving metal oxidation and other electrochemical reactions such as corrosion, to occur faster (Arash et al., 2019). Research has established that higher temperatures can lower the viscosity of electrolytes such as water or moisture layers, allowing corrosive ions such as chlorides to diffuse rapidly toward the metal surface thereby increasing corrosion rate (Qiannan et al., 2022). According to study, for many metals, a 100C rise in temperature doubles the corrosion rate. This heat-driven acceleration impacts several underlying electrochemical processes such as corrosion (Hanwen et al., 2024).

Figure 4 shows the comparative analysis of the corrosion rate of carbon steel in gas-flaring and non-gas flaring environments. The high level of gaseous pollutants such as sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO_2), particulate matter, and heat released into the environment due to gas-flaring activities have significantly altered atmospheric conditions (Opurum et al., 2025). Hence, these pollutants contribute to acid rain formation and increased atmospheric aggressiveness, thereby accelerating corrosion processes in a gas flare environment. The average corrosion rate of carbon steel in a gas flaring environment is 2.5 times higher than that in a non-gas flaring environment as determined in this study. This finding is in consonance with previous studies which reported severe corrosion of metallic structures situated in a gas flare environment (Opururm et al., 2025; Ify et al., 2016; Dung et al., 2008; Obia et al., 2011).

IV. CONCLUSION

This comparative study demonstrates that atmospheric corrosion of carbon steel is significantly more severe in gas-flaring environment of the Niger Delta than in non-gas flaring environment. The

increased corrosion rate is principally attributed to elevated temperatures, presence of nitrogen oxides, sulfur oxides, acidic precipitation, and particulate pollutants generated during gas flaring. The finding showed that carbon steel exposed in gas-flaring environment exhibited corrosion rates approximately two and half times higher than that observed in non-gas flaring environment. This study recommends the importance of implementing effective corrosion control measures to improve infrastructure durability and environmental sustainability in the Niger Delta.

Acknowledgment

I acknowledge my project students and the laboratory Technologists in Chemical and Petrochemical Engineering, Rivers State University, Port Harcourt, for their assistance throughout the period of the experiment.

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