
STUDY OF THE CORROSION RATE OF NIGERIAN HIGH-GRADE CONVENTIONAL 5 MM UKRAINIAN METALLIC PLATE USING WEIGHT LOSS (GRAVIMETRIC) METHOD

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ABSTRACT

Accurate estimation of corrosion rate is essential for predicting the service life of petroleum tanker materials. This study used the weight-loss/gravimetric technique to investigate corrosion of carbon-steel tanker-truck material in Automotive Gas Oil (AGO) and Premium Motor Spirit (PMS) over 63 days (1512 h). The gravimetric analysis revealed measurable degradation of the carbon-steel coupons following immersion in both petroleum products, with different magnitudes under the tested conditions. The AGO-exposed specimens recorded an average weight loss of 0.40 g, whereas the PMS-exposed specimens exhibited a mean weight loss of 0.20 g, indicating approximately 100% greater mass loss in AGO. Using the ASTM G31 corrosion-rate equation with $K = 8.76 \times 10^4$ for mm/year, an exposed area of 22.80 cm², an exposure time of 1512 h and a steel density of 7.85 g/cm³, the calculated mean corrosion rates were 0.129 mm/year for AGO and 0.065 mm/year for PMS. Thus, under the specific laboratory conditions and for the fuel batches tested, AGO produced approximately twice the gravimetric corrosion rate measured in PMS. Because the study did not determine the physicochemical properties of the fuel samples, the observed difference is reported without assigning it to sulphur content or any other individual fuel constituent.

Keywords: Corrosion rate; weight-loss method; ASTM G31; carbon steel; PMS; AGO

1. INTRODUCTION

Nigeria's energy security and downstream petroleum supply system depend substantially on the safe and reliable transportation of petroleum products by road tanker trucks, particularly in view of the limitations of pipeline and rail infrastructure (Ambituuni, 2016). Tanker trucks therefore constitute an important link between petroleum-product storage facilities and end users across the country. However, the continued occurrence of tanker-related fires, explosions and other loss-of-containment incidents demonstrates the persistent safety challenges associated with petroleum-product transportation in Nigeria. A 16-year national review reported 169 tanker fire and explosion accidents resulting in 1,613 deaths between 2009 and 2024 (Na'inna, 2024). The persistence and severity of these incidents underscore the need for a systematic, engineering-based approach to improving the safety and integrity of petroleum tanker systems.

Tanker safety is influenced by several interacting factors, including human behaviour, road and traffic conditions, vehicle condition, operational practices, regulatory enforcement and the integrity of the tanker itself. While human and operational factors have received considerable attention, the condition of the metallic tanker shell represents an important engineering aspect of containment integrity. The tanker shell serves as the primary barrier separating the transported petroleum product from the external environment. Progressive deterioration of this barrier can reduce its effective thickness and structural capacity and may eventually result in leakage or loss of containment. Among the mechanisms responsible for metallic deterioration, corrosion is particularly important because it is a progressive process that can occur during prolonged service and may remain unnoticed until significant material loss has occurred.

The interaction between tanker-shell material and the transported petroleum product is therefore an important area of investigation. In Nigeria, Premium Motor Spirit (PMS) and Automotive Gas Oil (AGO) constitute major petroleum products transported by road tankers. Their different physico-chemical characteristics may result in different interactions with carbon-steel tanker plates and, consequently, different rates of material degradation. However, the corrosion rate of the actual metallic material used for tanker fabrication under controlled exposure to these petroleum products requires experimental determination. Quantifying this material loss is important because corrosion rate provides a direct indication of the rate at which the tanker-shell thickness may progressively deteriorate.

The weight-loss (gravimetric) method provides a practical means of determining cumulative corrosion-induced metal loss. By measuring the difference between the initial and final masses of a metallic coupon after controlled exposure and relating the mass loss to the exposed surface area, material density and exposure duration, the average corrosion penetration rate can be quantified. The ASTM G31 standard provides guidance for laboratory immersion testing and offers an appropriate basis for controlled assessment of corrosion behaviour. Unlike an assessment based solely on visual surface deterioration, gravimetric analysis provides quantitative evidence of actual material loss during the specified exposure period.

This study applies the ASTM G31 gravimetric (weight-loss) method, the most widely used baseline technique for corrosion-rate estimation because of its simplicity and direct relationship to actual metal loss to a locally sourced, high-grade conventional 5 mm Ukrainian carbon steel plate (4.5 mm actual thickness) used for tanker fabrication in Nigeria, following 63 days of full immersion in PMS and AGO under ambient laboratory conditions.

2. LITERATURE REVIEW

The weight-loss (gravimetric) method is one of the most established experimental techniques for determining the corrosion rate of metallic materials. Its major advantage is that it provides a direct measure of actual metal loss during a defined exposure period. The method involves accurately weighing a prepared metal coupon before and after exposure to a corrosive environment, cleaning the specimen to remove corrosion products, and converting the resulting mass loss into a corrosion penetration rate. Because of its simplicity, relatively low cost and ability to quantify cumulative material loss, the method has been widely applied in studies of carbon and mild steel exposed to atmospheric, aqueous and petroleum-related environments. As cited in Guma & Abu, (2018), for example, applied gravimetric measurements in corrosion investigations, demonstrating the applicability of weight-loss analysis to steel corrosion studies.

The relevance of the gravimetric method to the Nigerian environment is demonstrated by Guma and Abu (2018), who investigated the atmospheric corrosion behaviour of mild steel around Kaduna metropolis. Their study involved a large number of corrosion coupons and used statistical analysis, including analysis of variance (ANOVA), to examine differences in corrosion behaviour associated with location. The authors reported statistically significant variations in corrosion rates among the investigated locations. This study is particularly relevant to the present research because it demonstrates the suitability of weight-loss measurements combined with statistical analysis for evaluating corrosion behaviour under Nigerian environmental conditions. The approach provides a useful methodological precedent for the present investigation of petroleum-tanker steel exposed to PMS and AGO.

A particularly relevant West African study was conducted by Suah (2014), who examined the corrosion behaviour of low-carbon steel containing approximately 0.184 wt.% carbon obtained from an above-ground petroleum storage tank in Liberia. The steel coupons were exposed to gasoline and diesel for periods of up to 456 h, while weight loss, pH and optical microscopy were used to monitor corrosion behaviour. The reported corrosion penetration rates ranged from approximately 0.016 to 0.325 mm/year, depending on the exposure medium and coupon. The study also observed a progressive reduction in solution pH during exposure. This behaviour was associated with the formation of acidic species, particularly carboxylic/acetic acid species, and their subsequent interaction with dissolved iron to form iron-containing corrosion products. The findings demonstrate that petroleum-derived fuels, despite being substantially less conductive than aqueous electrolytes, can still support measurable corrosion of carbon steel when appropriate corrosive species and

environmental conditions are present. The study therefore provides an important regional reference for investigating the interaction between tanker-fabrication steel and petroleum products.

Corrosion of Carbon Steel in Diesel and Biodiesel-Containing Fuels

A substantial body of literature has also investigated corrosion of carbon steel in diesel–biodiesel systems. Although biodiesel-containing fuels are not chemically identical to conventional Automotive Gas Oil (AGO), these studies provide useful comparative evidence because diesel and biodiesel systems contain oxygenated compounds and may exhibit different moisture, acidity and oxidation characteristics from lighter petroleum products such as PMS.

Cursaru et al. (2014) reported greater surface deterioration of mild carbon steel in biodiesel than in petroleum diesel, demonstrating the influence of fuel composition on steel corrosion. Similarly, Milano et al. (2021), Adama et al. (2024), and Adama et al. (2025) reported relationships between increasing biodiesel content and increasing corrosion severity. These findings indicate that changes in fuel composition can significantly modify the interaction between the fuel environment and carbon-steel surfaces.

Exposure configuration is also an important factor in petroleum-fuel corrosion. Kugelmeier et al. (2021) investigated carbon steel exposed to diesel–biodiesel blends and found comparatively limited attack under full-immersion conditions, while more pronounced deterioration occurred in the vapour phase. This observation is important for petroleum tanker applications because a tanker shell is not necessarily exposed to a single uniform environment. Depending on the fuel level, temperature, moisture accumulation and operating conditions, different regions of the tank may experience liquid-phase, vapour-phase and fuel–water interface exposure. Consequently, corrosion rate measurements obtained under full immersion should be interpreted as representing a defined experimental exposure condition rather than necessarily reproducing every corrosion mechanism occurring inside an operating tanker.

Further evidence was provided by Heryana et al. (2024), who investigated SA 516 Gr.70 carbon steel exposed to diesel–biodiesel blends. The study reported corrosion rates of approximately 1.226–1.442 $\mu\text{m}/\text{year}$, with corrosion severity increasing with biodiesel content. Surface examination using SEM/EDS revealed pitting and corrosion products containing predominantly iron and oxygen. These observations demonstrate the usefulness of combining gravimetric measurements with surface and elemental characterization to establish not only how much metal is lost, but also the nature of the resulting corrosion damage.

Corrosion Behaviour of Carbon Steel in AGO and PMS

While the studies involving diesel–biodiesel fuels provide useful information on fuel-related corrosion, direct investigations involving commercial AGO and PMS are particularly relevant to petroleum tanker applications in Nigeria. Shuaib-Babata and Abdulqadir (2012) investigated commercial low-carbon steel in several environments, including AGO, PMS, dual-purpose kerosene (DPK), crude oil, freshwater and seawater. Their reported corrosivity sequence was:

natural seawater > simulated seawater > freshwater > crude oil > PMS > DPK > AGO.

This result indicates considerably lower apparent corrosivity for AGO than for PMS under their experimental conditions. However, this ranking differs from the corrosion-rate trend obtained in the present investigation, where AGO exhibited a higher gravimetric corrosion rate than PMS. Such differences do not necessarily represent contradictions in the underlying corrosion behaviour; rather, they demonstrate the strong dependence of measured corrosion rate on the specific material, fuel composition and experimental conditions.

Differences between studies may arise from variations in steel composition and microstructure, fuel formulation, water and contaminant content, dissolved oxygen, temperature, exposure duration, specimen surface condition and exposure configuration. Petroleum fuels are complex mixtures rather than single chemical substances, and their corrosive behaviour can change considerably with storage history, contamination and the presence of water or other reactive species. Therefore, corrosion-rate values obtained from one fuel batch or steel grade should not automatically be assumed to represent all tanker operating conditions.

Relevance to the Present Study

The reviewed literature demonstrates that the corrosion of carbon-steel materials in petroleum-related environments is influenced by the interaction between the metallic material and the

characteristics of the exposure medium. The weight-loss method is particularly valuable for the present research because it measures cumulative mass loss and can therefore be directly related to the progressive loss of tanker-shell material. Previous Nigerian and West African studies have established the applicability of gravimetric techniques to steel corrosion, while investigations involving diesel, biodiesel, AGO and PMS demonstrate that corrosion behaviour can vary substantially with fuel composition and exposure conditions.

However, there remains a need for experimental data specifically addressing the corrosion rate of carbon-steel plates used for petroleum tanker fabrication in Nigeria when exposed directly to PMS and AGO under controlled conditions. In particular, the divergence between the AGO/PMS corrosion rankings reported in previous studies highlights the importance of generating experimental data from the actual tanker-fabrication steel and petroleum-product batches investigated in a given study, rather than relying solely on corrosion rates reported elsewhere.

Accordingly, the present study employs the ASTM G31-based weight-loss (gravimetric) method to quantify the corrosion rates of the investigated carbon-steel tanker plate following controlled immersion in PMS and AGO. By maintaining the same steel material, specimen preparation procedure, exposure conditions and measurement approach for both petroleum products, the study provides a direct basis for comparing their relative effects on the tanker-fabrication material. The resulting corrosion-rate data constitute the fundamental experimental evidence for subsequent evaluation of corrosion-induced material degradation, mechanical-property changes, corrosion mitigation and the implications of tanker-shell deterioration for leakage and fire/explosion risk in Nigeria.

3. MATERIALS AND METHODS

3.1 Materials

Fresh carbon steel plate of 4.5 mm actual thickness (locally referred to as high-grade conventional 5 mm Ukrainian metallic plate) was procured from Dan Magaji Tanker Fabricators, Zaria, Nigeria. Premium Motor Spirit (PMS) and Automotive Gas Oil (AGO) used for the study were purchased from AA Rano Filling Station, Sokoto Road, Zango, Samaru, Zaria.



Figure 3.1: The 4.5 mm carbon steel plate

3.2 Sample Preparation

Specimens were cut to the required dimensions using a power hacksaw machine, with care taken to avoid excessive heating that could alter the microstructure. Surface grinding was carried out manually using silicon carbide emery papers of progressively finer grit (220, 320, 400, 600 and 800), followed by polishing on a rotating polishing machine using an aluminium oxide slurry. Degreasing was performed by immersing the polished specimens in boiling alcohol for approximately 10 minutes, after which the specimens were dried using clean absorbent tissue paper prior to testing.



Figure 3.2: Prepared carbon steel coupons after grinding, polishing and degreasing before weighing

3.3 Immersion Procedure

A volume of 500 mL each of PMS and AGO was poured separately into clean plastic containers. Five specimens were tagged, weighed on an analytical balance to record the initial weight, and immersed separately in PMS and AGO. Containers were tightly sealed to minimise air ingress, contamination and evaporation. An exposure duration of approximately 63 days was adopted, comparable to immersion durations used in prior Nigerian corrosion studies of carbon steel in petroleum media (Shuaib-Babata & Abdulqadir, 2012). Specimens were visually inspected at 7 and 27 days; no significant corrosion products were observed at these intermediate points, but visible corrosion products were present by the end of the 63-day period.

After removal from the immersion media, loose corrosion products were gently removed using a soft brush. The specimens were then immersed in a hydrochloric acid (HCl) solution for 10 minutes to remove adherent corrosion products, rinsed thoroughly with distilled water followed by ethanol, and dried in a desiccator to eliminate residual moisture. The final weight of each specimen was measured using an analytical balance and weight loss was determined by taking the difference between initial and final weight of each sample.



Figure 3.3: Sealed plastic containers with carbon steel coupons immersed in PMS and AGO

3.4 Corrosion-Rate Calculation (ASTM G31)

The coupon dimensions were 64 mm × 13 mm × 4 mm, with all six surfaces exposed; the 4.5 mm actual material thickness was reduced to 4 mm due to machining during material preparation, the exposed surface area (top and bottom faces plus all four edges) was calculated as 22.80 cm². The corrosion rate in mm/year was estimated using the standard ASTM G31 weight-loss equation:

$$\text{Corrosion Rate (mm/year)} = (K \times W) / (A \times T \times D) \quad \text{Eq1}$$

where K is the unit-conversion constant. Using W in grams, A in cm², T in hours and D in g/cm³, the applicable constants are K = 3.45 × 10⁶ for mils per year (mpy), K = 8.76 × 10⁴ for millimetres per year (mm/year), and K = 8.76 × 10⁷ for micrometres per year (µm/year). Therefore, because the corrosion rates in this study are reported in mm/year, W is the weight loss in grams, A is the exposed surface area in cm², T is the exposure time in hours, and D is the density of the steel (7.85 g/cm³), the appropriate is K = 8.76 × 10⁴ based on.

$W/(A \cdot T \cdot D)$ has units $\text{g}/(\text{cm}^2 \cdot \text{h} \cdot \text{g}/\text{cm}^3) = \text{cm}/\text{h} \rightarrow$ a linear penetration rate

Converting cm/h → mm/year: $\times 10$ (cm → mm) $\times 8760$ (hours/year) =
 $\times 87,600 = 8.76 \times 10^4$

ASTM G31-72 quoted verbatim in two US patent filings: "*Corrosion rate = $8.76 \times 10^4 \times (\text{weight loss(g)}/(\text{area}(\text{cm}^2) \times \text{density}(\text{g}/\text{cm}^3) \times \text{time}(\text{h})))$* " — explicitly labelled mm/year in both.

The mean and standard deviation of the weight-loss measurements were calculated using the standard formulae for sample mean and standard deviation.

For verification, substitution of the mean values gives: $AGO = (8.76 \times 10^4 \times 0.40)/(22.80 \times 1512 \times 7.85) = 0.12948 \text{ mm/year}$, reported as 0.129 mm/year; and $PMS = (8.76 \times 10^4 \times 0.20)/(22.80 \times 1512 \times 7.85) = 0.06474 \text{ mm/year}$, reported as 0.065 mm/year. Thus, the reported rates follow directly from the stated mean weight losses, area, exposure time, density and the mm/year constant.



Figure 3.4: Corroded specimens after HCl cleaning, distilled-water/ethanol rinse and desiccator drying, immediately before final weight measurement on the analytical balance

4. RESULTS AND DISCUSSION

The weight-loss method was employed to evaluate the corrosion behaviour of carbon steel exposed to PMS and AGO over the 63-day immersion period. The results are presented in Table 1.

Table 1: Corrosion-rate of carbon steel in AGO and PMS media

Parameter	AGO	PMS
Mean Weight Loss (g)	0.40	0.20
Standard Deviation (g)	0.183	0.141
Exposed Surface Area (cm ²)	22.80	22.80
Density (g/cm ³)	7.85	7.85
Exposure Time Hour (h)	1512	1512
Mean Corrosion Rate (mm/year)	0.129	0.065

The gravimetric analysis revealed measurable degradation of the carbon steel coupons following immersion in both petroleum products; however, the degree of deterioration varied considerably between the two fuels. The AGO-exposed specimens recorded an average weight loss of 0.40 g, whereas the PMS exposed samples exhibited a mean weight loss of 0.20 g, the mass loss in diesel was approximately 100% greater than that observed in petrol under identical exposure conditions. The calculated corrosion rates followed the same trend: the average corrosion rate of

0.129 mm/year for AGO was approximately twice that obtained for PMS (0.065 mm/year), demonstrating that the carbon steel experienced a more aggressive corrosive environment in diesel than in petrol.

The higher corrosion rate measured in AGO should be interpreted as an experimental result obtained for the specific fuel batch and exposure conditions used in this study. The present experiment did not include physicochemical analysis of the PMS or AGO; therefore, the difference in corrosion rate cannot be attributed quantitatively to sulphur content, acidity, water content, dissolved oxygen, oxidation products or any other individual fuel constituent. Differences in fuel composition and contamination are possible explanatory factors identified in the wider literature, but their contributions were not measured here.

To place these corrosion rates in context, Suah (2014) reported broadly comparable, and in some cases lower, gravimetric corrosion penetration rates (0.016–0.325 mm/year) for low-carbon steel (0.184 wt% C) exposed to diesel and gasoline for up to 456 hours (19 days) under similarly uncontrolled ambient laboratory conditions. Although the fuel media are not identical (Liberian diesel/gasoline versus Nigerian AGO/PMS), the two studies together suggest that carbon steel corrosion rates in petroleum products of this kind typically fall within a comparable low sub-millimetre-per-year range, well below corrosion rates reported for carbon steel in aqueous or marine environments (Guma & Abu, 2018). Reported values are sensitive to exposure duration, coupon geometry and the specific carbon content of the steel investigated, so direct numerical comparison across studies should be treated as indicative rather than exact.

The difference between the AGO and PMS results therefore demonstrates that the corrosivity ranking obtained in this experiment is specific to the investigated steel, fuel batches and controlled exposure conditions. Without direct physicochemical testing of the two fuel samples and without presenting the steel composition in this manuscript, the present data do not permit a definitive mechanistic explanation for why AGO produced the higher rate.

The gravimetric result that AGO produced a substantially higher corrosion rate (0.129 mm/year) than PMS (0.065 mm/year) contrasts with Shuaib-Babata and Abdulqadir (2012), who tested commercial low-carbon steel in AGO, PMS, DPK, crude oil and seawater and reported AGO as the least corrosive petroleum fraction in their weight-loss study, the reverse of the ranking obtained here. The two studies used different steel materials, fuel samples and exposure conditions, including different temperature regimes. Consequently, the discrepancy should not be used to infer a universal corrosivity ranking between AGO and PMS. Rather, it supports the present study's rationale that corrosion-rate measurements should be generated for the specific material and fuel environment under investigation. Because this manuscript does not present the bulk chemical composition of the investigated plate, no claim is made here that the material is medium-carbon steel or that composition alone explains the difference from the earlier study.

The present result can also be discussed alongside diesel-biodiesel corrosion studies with appropriate caution. Heryana et al. (2024), for example, reported measurable corrosion and pitting of SA 516 Gr.70 carbon steel in diesel-biodiesel and diesel-biodiesel-HVO blends, with corrosion severity varying with blend composition. Those results reinforce the broader finding that fuel composition and exposure conditions can influence carbon-steel corrosion, but they do not establish that conventional AGO is inherently more corrosive than PMS. Accordingly, the present AGO>PMS ranking should be limited to the tested fuel batches and 63-day ambient laboratory immersion conditions. Further work should include physicochemical characterization of the fuel samples and independent material-composition data to investigate the mechanisms responsible for the observed difference.

5. CONCLUSION

The corrosion behaviour of the investigated carbon steel plate, locally referred to as high-grade conventional 5 mm Ukrainian metallic plate and measured as 4.5 mm before coupon machining, was evaluated after 63 days (1512 h) of full immersion in PMS and AGO using the ASTM G31 gravimetric (weight-loss) approach. Under the specific laboratory conditions and for the fuel batches tested, both media produced measurable weight loss. AGO produced a mean corrosion rate of 0.129

mm/year, approximately twice the 0.065 mm/year measured for PMS. The result establishes the relative severity observed in this experiment but does not demonstrate that AGO is universally more corrosive than PMS or identify a specific fuel constituent as the cause because the fuel physicochemical properties were not measured. The findings support the need for material- and fuel-specific corrosion assessment, and future studies should combine gravimetric testing with fuel physicochemical characterization and independent material-composition analysis before making mechanistic or general corrosivity claims.

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