
OPTICAL EMISSION SPECTROSCOPY (OES) ANALYSIS OF CORROSION OF HIGH-GRADE CONVENTIONAL 5 MM UKRAINIAN METALLIC PLATE USED IN TANKER TRUCK FABRICATION IN NIGERIA

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ABSTRACT

Elemental compositional analysis (OES) provides a metallurgical basis for interpreting corrosion severity in tanker steel beyond what mass-loss or electrochemical measurements alone can show. This research studies changes in the elemental composition of carbon steel metallic plate due to corrosion in PMS and AGO medium using bulk Optical Emission Spectroscopy (OES). The study considers control (unexposed), PMS-corroded and AGO-corroded coupons of high-grade conventional 5 mm Ukrainian carbon steel plate (4.5 mm actual thickness) used for tanker fabrication in Nigeria, following 63-day immersion at ambient temperature. OES showed a progressive decrease in iron content from 98.251 wt.% (control) to 98.052 wt.% (PMS) and 97.700 wt.% (AGO), determined by mass-balance difference from the fully quantified element set, accompanied by a corresponding relative enrichment of carbon, chromium, copper and tungsten, consistent with preferential anodic dissolution of iron. The elemental trends from bulk OES confirm AGO as the more aggressive corrosive medium than PMS.

Keywords: Carbon steel; OES; elemental composition; corrosion; PMS; AGO

1. INTRODUCTION

Road transportation remains the dominant means of transporting refined petroleum products, including Premium Motor Spirit (PMS) and Automotive Gas Oil (AGO), from depots to retail outlets across Nigeria, with tanker trucks constructed predominantly from carbon steel forming the backbone of this distribution network. Existing studies on Nigerian petroleum tanker safety have focused heavily on policy, logistics, driver behaviour, and regulatory enforcement, leaving the material integrity of the tanker shell relatively underexamined. Mass-loss (gravimetric) and electrochemical (potentiodynamic polarization) techniques can quantify the amount of metal lost and the rate of electrochemical dissolution due to corrosion, respectively; however, neither technique directly reveals how the bulk metallurgical composition of the steel changes as corrosion progresses. Optical Emission Spectroscopy (OES) provides rapid and quantitative determination of bulk elemental composition and is therefore well suited to tracking compositional changes associated with corrosion, providing a metallurgical perspective on the same degradation process captured by weight-loss and electrochemical measurements.

This study applies bulk OES to control (unexposed), PMS-corroded, and AGO-corroded coupons of a high-grade conventional 5 mm Ukrainian carbon-steel plate (4.5 mm actual thickness) used for tanker fabrication in Nigeria. The coupons were fully immersed in PMS and AGO for 63 days under ambient laboratory conditions. The study aimed to investigate corrosion-induced changes in the elemental composition of the carbon-steel plate following exposure to PMS and AGO and to compare the compositional changes associated with the two petroleum-product media.

2. LITERATURE REVIEW

Optical Emission Spectroscopy (OES) is an established analytical technique for determining the elemental composition of metallic materials and is particularly useful for rapid quantitative

characterization of carbon steels. In corrosion research, elemental characterization is important because the chemical composition of steel influences its microstructure, mechanical properties and susceptibility to environmental degradation. Ishtiaq et al. (2022), for example, combined OES with Scanning Electron Microscopy and Energy-Dispersive Spectroscopy (SEM/EDS) to investigate the relationship between elemental composition, microstructure and corrosion behaviour of AISI carbon steels. Their findings indicated that steels with relatively fine ferrite–pearlite microstructures exhibited lower corrosion susceptibility than steels with coarser or more heterogeneous microstructures. This demonstrates the value of combining elemental and microstructural characterization when evaluating the corrosion behaviour of carbon-steel materials.

The importance of elemental composition to the performance of carbon steel has also been demonstrated using other analytical techniques. Borisade et al. (2021) employed X-ray fluorescence (XRF), a related elemental-characterization technique, to investigate the relationship between chemical composition and mechanical properties of carbon steel. Although their study did not involve corrosion exposure, it demonstrated that elements such as carbon and manganese, together with residual alloying elements, influence important mechanical properties such as strength and toughness. These findings are relevant to tanker-truck fabrication because variations in the chemical composition of locally sourced or fabricated steel plates may influence both their initial mechanical performance and subsequent susceptibility to corrosion.

An important consideration when applying OES to corroded steel is the interpretation of changes in elemental weight percentages. An apparent increase in the relative concentration of an alloying element after corrosion does not necessarily indicate that the element has been introduced into, or accumulated in, the steel. Rather, it may result from preferential dissolution of iron from the sampled metallic region, leaving the remaining alloying elements relatively enriched in percentage terms. Thus, an increase in the measured percentage of Mn, Si, Cr or other elements after exposure should not automatically be interpreted as an increase in their absolute mass.

This interpretation is consistent with the classical concept of preferential dissolution in iron-based alloys described by Marshakov (2002), whereby different alloy constituents may dissolve at different rates during anodic corrosion. More recent observations by Kowalczyk et al. (2025) further demonstrate the importance of selective corrosion in steel components. Their investigation of steel pipeline welds reported localized corrosion pits reaching substantial depths and associated deterioration in mechanical performance, illustrating the relationship between localized material degradation and structural integrity.

Accordingly, in the present study, changes in OES-determined elemental percentages between the unexposed control steel and the PMS- and AGO-exposed specimens are interpreted primarily as relative compositional changes within the sampled metallic material, rather than as evidence that new alloying elements were generated or added during corrosion. This distinction is essential for scientifically valid interpretation of OES results. Although OES provides quantitative elemental information, it does not by itself provide a complete description of the physical morphology of corrosion damage.

Despite the established use of OES and related elemental techniques for characterizing carbon steels, several important limitations remain in the existing literature. First, previous studies such as Ishtiaq et al. (2022) have demonstrated the usefulness of combining OES with SEM/EDS for relating steel composition and microstructure to corrosion behaviour, but their investigation was not specifically concerned with carbon-steel plates used in petroleum tanker-truck fabrication under Nigerian operating conditions.

Second, Borisade et al. (2021) demonstrated the relationship between elemental composition and mechanical properties using XRF, but their work considered the initial material condition rather than corrosion-induced compositional changes. Consequently, it does not establish how the elemental composition of carbon-steel plate changes following exposure to petroleum products.

Third, much of the petroleum-fuel corrosion literature has concentrated on gravimetric weight loss, electrochemical polarization and surface morphology, with studies by Cursaru et al. (2014), Heriyana et al. (2024), Adama et al. (2024, 2025), Chile et al. (2022) and Kugelmeier et al. (2021) providing evidence of corrosion through one or more of these approaches. However, these studies provide limited information on the elemental-compositional dimension of corrosion of tanker-grade carbon-steel plates. This limitation is particularly significant for Nigeria, where carbon-steel plates are widely

relevant to petroleum-product transportation and where locally fabricated tanker bodies may experience variable material quality, fabrication practices and service conditions.

The specific research gap addressed by this study is therefore elemental and corrosion assessment of carbon-steel tanker-fabrication plates exposed to PMS and AGO under Nigerian-relevant conditions using OES. The present study addresses this gap by applying OES to establish the elemental composition of the unexposed carbon-steel plate; determine the elemental composition after controlled exposure to PMS; determine the elemental composition after controlled exposure to AGO; identify changes in the relative concentrations of major alloying and residual elements; interpret these changes in relation to preferential/selective dissolution during corrosion

3. MATERIALS AND METHODS

3.1 Materials and Baseline Characterization

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. To establish the baseline characteristics of the material and verify its authenticity, the specimen was characterized using Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy (SEM-EDS) at the Nigerian Building and Road Research Institute (NBRRI), Abuja, and Optical Emission Spectroscopy (OES) at the Defence Industries Corporation of Nigeria (DICON), Kaduna. The OES analysis was used to determine the bulk chemical composition of the carbon steel, while the SEM-EDS analysis characterized the surface morphology and provided supporting elemental information.



Figure 3.1: The 4.5 mm carbon steel plate

3.2 Corrosion Exposure

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. A volume of 500 mL each of PMS and AGO was poured separately into clean plastic containers, and carbon steel coupons were immersed separately in each medium for an exposure period of approximately 63 days (14/04/2026 to 16/06/2026) under ambient laboratory temperature conditions (approximately 25–33°C, not actively controlled). Containers were tightly sealed to minimise air ingress, contamination and evaporation, and the fuel charge in each container was not replenished or topped up at any point during the 63-day exposure period; the single-charge, sealed-container configuration was adopted specifically to limit evaporative loss of the volatile PMS fraction. After removal from the immersion media, loose corrosion products were gently removed using a soft brush, and the specimens were immersed in a hydrochloric acid (HCl) solution for 10 minutes to remove adherent corrosion products, rinsed with distilled water followed by ethanol, and dried in a desiccator prior to analysis.



Figure 3.2: Sealed plastic containers with carbon steel coupons immersed in PMS and AGO

3.3 OES Analysis

Optical Emission Spectroscopy was conducted on three sets of coupons: control (unexposed), PMS-corroded (P) and AGO-corroded (D) carbon steel samples, to determine the bulk elemental composition and evaluate the compositional changes associated with prolonged immersion in the two petroleum products. Because OES reports elemental composition as a weight percentage of a fixed near-surface sampled volume, any reduction in iron content caused by anodic dissolution mathematically raises the weight-percentage share of every element that remains, even though the absolute mass of those elements in the specimen has not increased. Increases recorded for carbon, chromium, copper, tungsten, manganese and other elements after exposure are therefore interpreted throughout this study as relative enrichment arising from preferential iron dissolution, consistent with the classical preferential-dissolution mechanism described by Marshakov (2002), rather than as evidence of new alloying elements entering the steel. Iron content is reported to three decimal places throughout this paper as the mass-balance difference, $\text{Fe wt.\%} = 100 - \Sigma (\text{all other quantified elements})$, for internal consistency with the other, directly measured elements; this calculation is applied consistently across Tables 1–3. Each specimen (control, PMS-corroded, AGO-corroded) was analysed by a single bulk OES scan, without replicate sparking or a separately reported standard deviation; this single-scan approach is a limitation of the present dataset, and replicate OES scans per condition are recommended for future work to allow measurement precision and reproducibility to be quantified.

4. RESULTS AND DISCUSSION

4.1 Baseline (Fresh) Elemental Composition

The baseline OES elemental composition of the fresh carbon steel is presented in Table 1.

Table 1: Fresh carbon steel OES elemental composition

Element	OES Weight %
Fe	98.251
C	0.408
Mn	0.425
Si	0.129
Cr	0.126
Ni	0.037
Cu	0.475
Nb	0.038
W	0.044
O	ND
Others	Trace

According to the OES analysis, the steel consists predominantly of iron (98.251 wt%), confirming that it is an iron-based structural steel. Carbon (0.408 wt%) is the principal strengthening element, placing the material in the medium-carbon steel category according to the standard ASTM/SAE carbon-content classification scheme (0.25–0.60 wt% C). Manganese (0.425 wt%) improves tensile strength, hardenability and wear resistance, while silicon (0.129 wt%) acts as a deoxidizer during steelmaking. The low concentrations of chromium, nickel and copper indicate that the material is a plain carbon steel with only residual alloying elements, and the negligible sulphur and phosphorus content is consistent with the compositional requirements of ASTM A36/A36M structural carbon steel. The OES carbon value (0.408 wt%) is used for alloy classification throughout this study.

4.2 Elemental Composition After Corrosion Exposure

Table 2 presents the OES elemental composition of the control, PMS-corroded and AGO-corroded carbon steel specimens after the 63-day exposure period.

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Table 2: OES elemental composition of carbon steel control, PMS-corroded and AGO-corroded

Element (wt. %)	Control	PMS (P) corroded	AGO (D) corroded	Observation
Fe	98.251	98.052	97.700	Progressive decrease
C	0.408	0.530	0.730	Relative enrichment
Si	0.129	0.126	0.129	Essentially unchanged
Mn	0.425	0.444	0.483	Slight relative enrichment
Cr	0.126	0.133	0.155	Relative enrichment
Ni	0.037	0.052	0.037	Slight fluctuation
Cu	0.475	0.493	0.550	Relative enrichment
Nb	0.038	0.039	0.041	Slight relative enrichment
W	0.044	0.061	0.098	Marked relative enrichment
Ce	0.015	0.017	0.020	Slight relative enrichment
La	0.052	0.053	0.057	Slight relative enrichment
Zr	0.0000	0.0000	0.0000	Not detected

The control specimen exhibited an iron content of approximately 98.251 wt.%, confirming that the investigated material is predominantly a carbon steel, with a carbon content of 0.408 wt.% and manganese content of 0.425 wt.% indicating a medium-carbon steel with minor alloying additions of chromium, copper, nickel, niobium and tungsten. This control composition provides the baseline against which the changes induced by petroleum product exposure are evaluated.

Following immersion in PMS, the iron content decreased slightly from approximately 98.251 wt.% to 98.052 wt.%, indicating dissolution of the steel matrix during corrosion. Simultaneously, the apparent carbon concentration increased from 0.408 wt.% to 0.530 wt.%, while chromium, copper, tungsten, niobium and manganese also exhibited slight increases. As iron corrodes and is removed from the surface, the remaining alloying elements become relatively enriched within the analysed volume, resulting in higher measured weight percentages; the relatively small reduction in iron indicates that PMS produced only moderate degradation of the steel during the immersion period.

The AGO specimen exhibited the greatest compositional changes among the three samples. Iron decreased further to approximately 97.700 wt.%, representing the largest reduction observed. At the same time, carbon increased to 0.730 wt.%, chromium increased to 0.155 wt.%, copper to 0.550 wt.%, tungsten to 0.098 wt.%, and manganese to 0.483 wt.%, with lanthanum and cerium also showing slight enrichment. The greater reduction in iron demonstrates that AGO promoted more extensive dissolution of the steel matrix than PMS, and the enrichment of the remaining alloying elements became correspondingly more pronounced. The particularly noticeable increase in tungsten and copper suggests stronger preferential dissolution of iron in the diesel environment, providing metallurgical evidence that corrosion damage was more severe in AGO than in PMS. One element does not follow this general enrichment pattern: nickel rose from 0.037 wt.% (control) to 0.052 wt.% (PMS) before returning to 0.037 wt.% (AGO), rather than increasing monotonically with corrosion severity as C, Cr, Cu and W do. Given that Ni is present only at trace level (0.037–0.052 wt.%, among

the lowest concentrations quantified in this study), this fluctuation is most plausibly attributable to local heterogeneity in the sparked volume and measurement-level variability near the OES detection/quantification limit for this element, rather than to a distinct corrosion mechanism selectively affecting nickel; the single-scan measurement approach used in this study (Section 3.3) cannot distinguish between these possibilities; and replicate OES scans, recommended above, would be needed to establish whether the Ni trend is reproducible or is measurement noise.

4.3 Relationship Between OES Results and Independently Measured Corrosion Rates

One of the major strengths of this study is that the OES findings are fully supported by the gravimetric corrosion measurements independently obtained for the same steel and fuel media, reported in a companion submission to this conference (Jamilu et al., 2026b), as summarised in Table 3.

Table 3: Comparison of OES result with weight loss corrosion rates result

Method	AGO Corroded	PMS Corroded
Weight-loss corrosion rate (mm/year)	0.129	0.065
OES Fe Content (%)	97.700	98.052

Both methods independently identify AGO as producing greater corrosion than PMS. The OES analysis demonstrated the greatest reduction in iron content in the AGO specimen, while the gravimetric technique measured the highest corrosion rates for the same medium. This agreement confirms that the elemental changes observed by OES are a direct consequence of increased corrosion activity, rather than measurement artefact. Loss of iron from the steel matrix reduces the effective load-bearing wall thickness and can increase local stress concentration at corrosion pits and other surface irregularities. General corrosion-engineering practice treats bulk iron loss of the kind measured here by OES as a precursor to, rather than direct proof of, mechanical-property degradation; direct tensile and impact testing of the corroded specimens was outside the scope of the present, OES-focused study and is not reported here.

The progressive depletion of iron and relative enrichment of Cr, Cu, W and Mn measured by OES in the corroded specimens, more pronounced in AGO than PMS, mirrors the compositional-change approach of Ishtiaq et al. (2022), who combined optical emission spectrometry with SEM/EDS to link elemental changes to corrosion severity and microstructure in AISI carbon steels; their finding that elemental shifts intensified with more susceptible microstructures parallels the moderate iron loss observed here, consistent with the relatively corrosion-resistant ferrite-pearlite microstructure of the investigated steel. Borisade et al. (2021), although their study did not involve corrosion exposure, demonstrated that manganese, carbon and residual alloying elements govern strength and toughness in carbon steel generally, which is consistent with, though does not itself confirm, a mechanistic link between the OES-measured post-corrosion enrichment of these elements and potential mechanical-property change; direct verification of this link would require tensile and impact testing of the corroded specimens, which was outside the scope of the present study.

Because the OES elemental trend agrees with the corrosion-rate ranking obtained by weight loss, and is consistent with the composition-corrosion relationships reported by Ishtiaq et al. (2022) and Borisade et al. (2021), OES can be regarded as a reliable, complementary indicator of near-surface metal loss. For petroleum tanker safety, periodic OES or portable XRF spot-checks on tanker shell coupons could provide an early, non-destructive warning of cumulative iron loss before it manifests as a measurable reduction in wall thickness or mechanical performance.

5. CONCLUSION

Bulk Optical Emission Spectroscopy (OES) was used to characterise the elemental composition of control, PMS-corroded and AGO-corroded coupons of high-grade conventional 5 mm Ukrainian carbon steel plate used for tanker fabrication in Nigeria, following 63 days of full immersion. OES revealed a progressive decrease in iron content from 98.251 wt.% (control) to 98.052 wt.% (PMS) and 97.700 wt.% (AGO), accompanied by a corresponding relative enrichment of

carbon, chromium, copper and tungsten in the corroded specimens, consistent with preferential anodic dissolution of iron. The elemental trends measured by OES agree fully with the corrosion-severity ranking (AGO > PMS) independently obtained by gravimetric weight-loss method on the same steel and fuel media (Jamilu et al., 2026b), and point toward a plausible metallurgical basis for corrosion-related mechanical-property loss in tanker steel, worth confirming with direct tensile and impact testing in future work. The findings confirm that bulk OES is a reliable, rapid and non-destructive complementary technique for tanker corrosion diagnostics, and support the use of periodic OES or portable XRF spot-checks on in-service tanker shell coupons as an early warning tool for cumulative corrosion-related iron loss in the Nigerian petroleum transportation sector.

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