Technical Report: Characterization of Diesel Fuel with a Graphene-Based Nanoadditive

Project: Graphene-Based Nanoadditive for Liquid Fuels

Date: April 14, 2026

1. Executive Summary

This report documents the physicochemical characterization and emissions performance evaluation of a commercial diesel fuel with a graphene-based nanoadditive, prepared at a final concentration of 8 ppm in fossil diesel. The concentrated additive formulation was prepared and supplied by the applicant; the blends submitted for evaluation were provided pre-agitated for analysis and technical validation.

Laboratory and engine performance tests were conducted in a comparative framework between the baseline diesel fuel and the GO-enhanced sample, following applicable ASTM methods for physicochemical property measurements and instrumental emissions measurement procedures. Overall, the results show that the nano additive preserves the fuel's operational properties while producing meaningful improvements in exhaust opacity, NOx emissions, and gravimetric fuel consumption.

The main findings were as follows:

- Density remained essentially unchanged, from 0.8226 to 0.8227 g/cm³.
- Kinematic viscosity at 40 °C showed a marginal variation (control: 2.5824 mm²/s, GO-Enhanced sample: 2.6007 mm²/s), remaining within a range compatible with conventional injection systems.
- The higher heating value increased from 45.50 to 45.76 MJ/kg, equivalent to a 0.57% increment.

- The complete degradation temperature extended to 317 °C, 52 °C above the fossil diesel reference (265 °C).
- Exhaust opacity decreased from 17.90% to 1.59%, with a concomitant reduction of the extinction coefficient K from 0.460 to 0.040 m^{-1}.
- NOx emissions during treatment were reduced from ~325 ppm (baseline) to ~218 ppm on average, a reduction of approximately 33% relative to the baseline.
- The fuel consumption rate decreased progressively from 0.0642 kg/min to 0.0562 kg/min, achieving a 12.5% reduction in the post-treatment run.

2. Experimental Methodology

2.1 Additive and Sample Preparation

The evaluated material was a graphene-based additive prepared by the applicant in a concentrated formulation consisting of 1.5 g of active phase dispersed in 125 mL of a hexane mixture with 5% biodiesel. The detailed composition of the active phase is maintained as confidential industrial information; however, for the purposes of this validation, the system is functionally described as a graphene-based additive stabilized in an organic matrix compatible with liquid fuels.

From this concentrated formulation, all test samples were prepared by dilution in fossil diesel to a single final additive concentration of 8 ppm. The blends used in the evaluations were prepared and supplied by the applicant, who delivered them pre-agitated, without additional sophisticated conditioning steps by the receiving laboratory prior to experimental use.

Two working conditions were considered for the comparative tests: i) commercial diesel (ULSD) as the negative control, and ii) fossil diesel GO-Enhanced with graphene-based nano additive at 8 ppm as the evaluation sample. A post-treatment condition with non-GO-Enhanced diesel was also included in the engine protocol to identify possible residual conditioning effects on the combustion system.

2.2 Physicochemical Characterization

Fuel characterization was performed in accordance with applicable ASTM methods, using the instrumentation listed below:

- Higher heating value: ASTM D4809, using a Parr 6200 calorimeter.
- Thermal stability (TGA): ASTM E1131, under inert nitrogen (N_2) atmosphere.
- FT-IR Spectroscopy: ASTM E1252, using a Perkin Elmer Frontier spectrometer.
- Kinematic viscosity, dynamic viscosity, and relative density: ASTM D7042, using a Stabinger SVM-3001 viscometer-densimeter.

2.3 Engine Evaluation and Operating Conditions

Exhaust gas emissions and fuel consumption were evaluated on a FAW diesel engine used as the reference platform. NOx measurements were performed using a Bacharach combustion analyzer, while opacity and the extinction coefficient K were determined with a Eurosmoke 9011 opacimeter complementary to the TameXSA MOTORSCAN unit.

All dynamic tests associated with opacity, gaseous contaminants, and fuel consumption were conducted under stabilized engine conditions at 70 °C and 1800 rpm constant, with a 20-minute stabilization period prior to each test. The experimental design followed a before/during/after sequence in order to compare the performance of the baseline diesel, the GO-Enhanced fuel, and the post-treatment diesel.

3. Results and Discussion

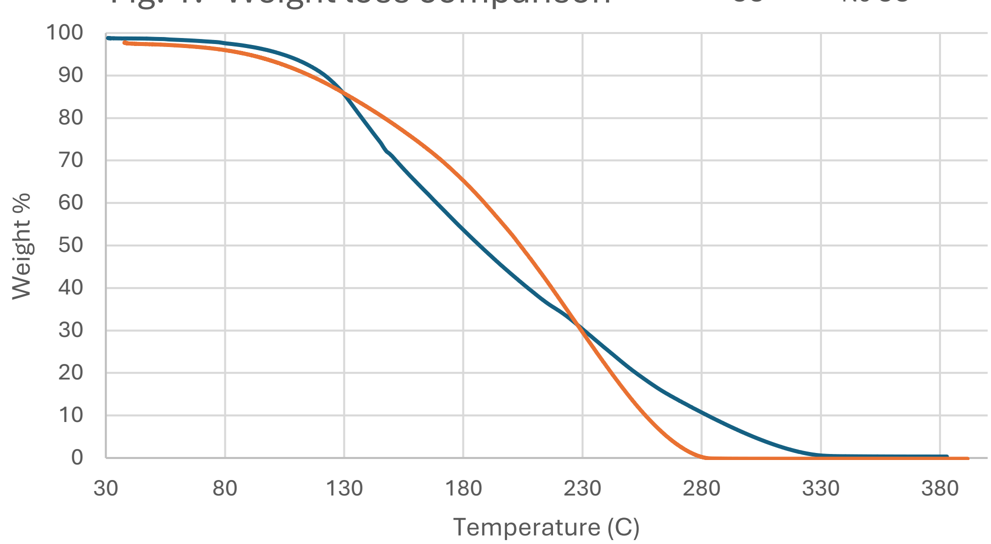
3.1 Energy Efficiency

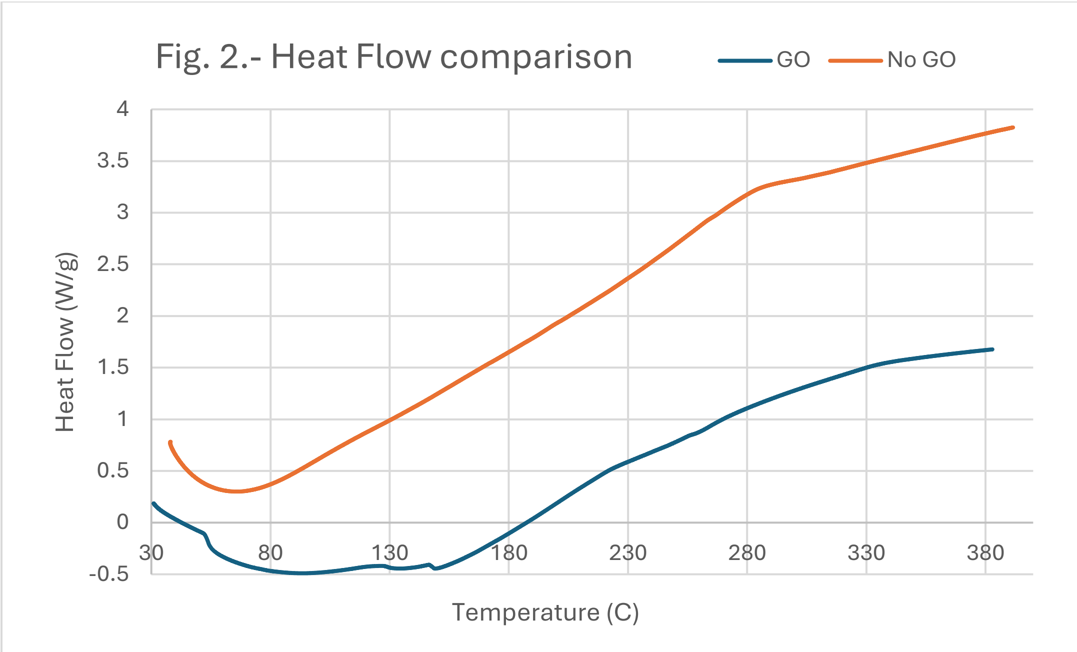
The negative control presented a higher heating value of 45.50 MJ/kg, while the GO-Enhanced sample reached 45.76 MJ/kg. The observed difference corresponds to a 0.57% increase, suggesting that the incorporation of the additive does not penalize the fuel's energy content and may promote slightly higher energy release under the conditions analyzed.

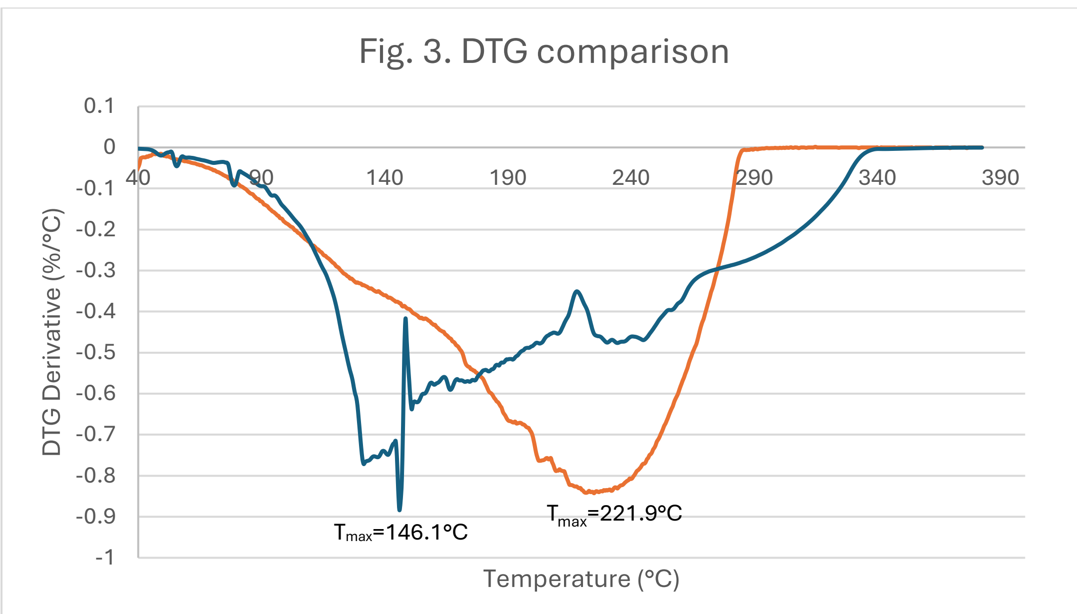
3.2 Thermal Analysis

The thermogravimetric curves (Fig. 1) showed a degradation onset at 88.6 °C for the fossil diesel and at 90.4 °C for the GO-Enhanced sample, both determined at a heating rate of 30 °C/min under inert N_2 atmosphere. The temperature of maximum mass loss rate (Tmax), determined from the DTG curve (derivative thermogravimetry), was 231.3 °C for the fossil diesel and 146.0 °C for the GO-Enhanced sample (Fig. 3). The shift of Tmax toward lower temperature in the GO-Enhanced sample is attributable to the presence of the carrier vehicle (hexanes), whose volatilization preferentially occurs between 100 and 160 °C. Nevertheless, the GO-Enhanced sample retains appreciable mass up to 317 °C, compared to 265 °C for the control, representing a 52 °C extension in the complete degradation temperature (<2% residual mass).

Fig. 1.- Weight loss comparison





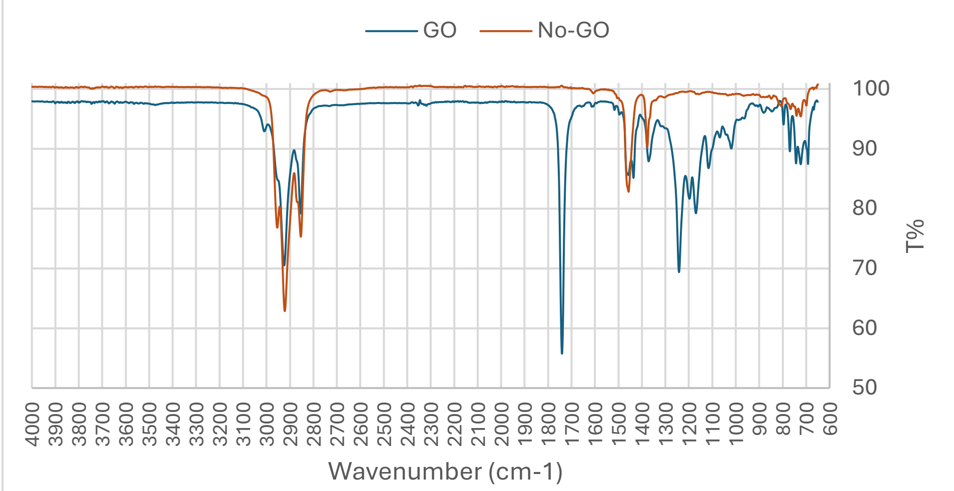


Heat flow analysis (DSC) indicated endothermic behavior in the GO-Enhanced sample up to approximately 190 °C, with the exothermic peak shifted to 382.8 °C compared to 297.7 °C for the fossil diesel reference, and a reduction in peak heat flow from 2.097 to 1.677 W/g (−20%). This behavior is consistent with the presence of stabilizing components and a modification of the thermochemical profile of the GO-Enhanced system (Fig. 2).

3.3 FT-IR Spectroscopy

FT-IR spectra confirmed that the hydrocarbon matrix dominates the overall chemical signature of the fuel. However, the GO-Enhanced sample showed an increase in the 1750 cm^{-1} band, attributable to the carbonyl group stretching associated with the biodiesel used as a stabilizing agent within the formulated system.

Fig. 4.- Diesel FTIR comparison



3.4 Relative Density and Viscosity

The negative control yielded a relative density of 0.8226 g/cm^3, a kinematic viscosity of 2.5824 mm^2/s, and a dynamic viscosity of 2.1244 mPa·s, all reported at 40 °C.

The GO-Enhanced sample yielded a relative density of 0.8227 g/cm^3, a kinematic viscosity of 2.6007 mm^2/s, and a dynamic viscosity of 2.1396 mPa·s, all reported at 40 °C.

From the above results, it is concluded that the GO-Enhanced sample maintains the same density and exhibits a negligible increase in viscosity; it showed no increase in density and falls within the applicable standard.

4. Opacity Reduction Results

4.1. Measurement Conditions

Exhaust opacity measurements were performed on March 27, 2026, using a TameXSA MOTORSCAN opacimeter (Serial No. 31800484, Software Version 2011.1.4). The tested sample corresponded to fossil diesel GO-Enhanced with graphene-based additive at a final concentration of 8 ppm, prepared from the concentrated formulation delivered by the applicant and pre-diluted in the base fuel.

During the evaluation, the engine was operated at a constant 70 °C and 1800 rpm, with a 20-minute stabilization period prior to data collection. The recorded instrumental conditions for both the control and the GO-Enhanced sample included a gas temperature of 32 °C and a tube temperature of 88 °C.

Parameter	**Negative Control (Diesel)**	**GO-Enhanced Sample**
Gas Temperature (°C)	32	32
Tube Temperature (°C)	88	88
Thermocouple Temperature	0	0
Speed	0	0

4.2. Opacity Measurement Results

Parameter	**Negative Control (Diesel)**	**GO-Enhanced Sample**
Opacity (%)	17.90	1.59
Extinction Coefficient K (m^{-1})	0.460	0.040
Measurement Timestamp	27/03/2026 – 03:38:18 p.m.	27/03/2026 – 03:49:14 p.m.

4.3 Technical Interpretation

The reduction in opacity from 17.90% to 1.59% represents a relative decrease of 91.1%, while the extinction coefficient K was reduced by 91.3%. Under the conditions of this study, these results support that the graphene-based formulation, applied at a final concentration of 8 ppm in fossil diesel, is associated with a marked reduction of visible particulate matter in the exhaust.

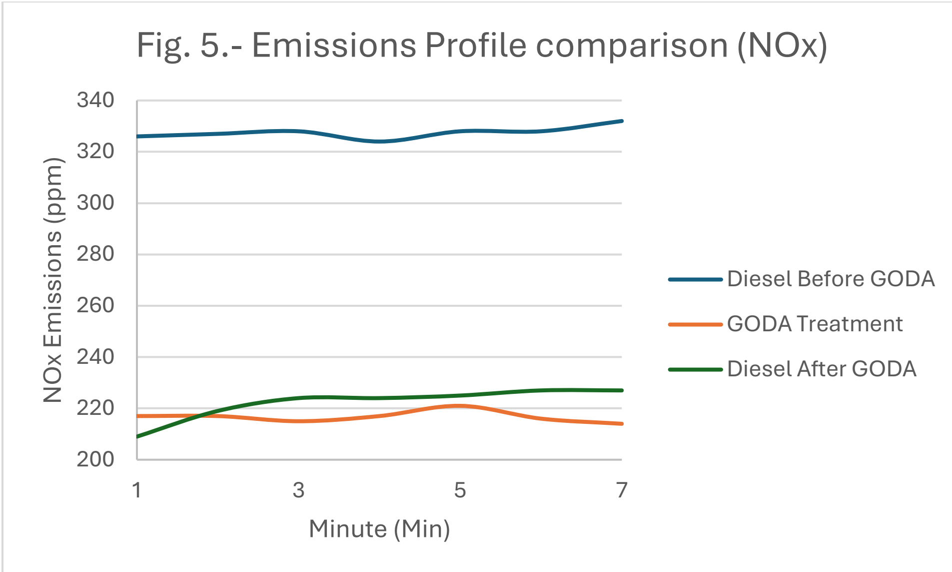
From an interpretive standpoint, this behavior is consistent with the slight increase in higher heating value, the improvement in thermal stability, and the preservation of viscosity and density within operationally compatible values. Consequently, the reduction in opacity can be reasonably attributed to more complete combustion and reduced formation of carbonaceous particulates under the evaluated regime.

5. NOx Emissions and Fuel Efficiency Analysis

5.1. NOx Emission Profile

The baseline diesel showed stable concentrations between 323 and 333 ppm, while during treatment with the additive, the range was reduced to 215–220 ppm (Fig. 4). The diesel evaluated after treatment maintained a profile of 207–230 ppm, suggesting a residual conditioning effect on the combustion system.

The approximate average 33% decrease in NOx during treatment is consistent with a favorable modification of the combustion environment. Technically, this may be associated with a reduction in local peak temperature zones or with improved fuel oxidation quality, without this interpretation replacing specific mechanistic studies.



5.2. Fuel Consumption Analysis

Gravimetric consumption was measured in three consecutive runs using a precision scale:

Run	**Duration**	**Consumption**	**Consumption Rate**
Diesel (Pre-additive)	11 min	0.706 kg	0.0642 kg/min
GO Additive Treatment	11 min	0.667 kg	0.0606 kg/min
Diesel (Post-additive)	12 min	0.674 kg	**0.0562 kg/min**

The three runs follow a before/during/after protocol, in which the post-additive run used untreated diesel in an engine that had been previously conditioned with the additive treatment. This design allows evaluation of both the direct effect of the additive and its residual conditioning influence on the combustion system.

Consumption rates decreased progressively across the three runs:

- From 0.0642 kg/min (baseline diesel).
- To 0.0606 kg/min during additive treatment (a 5.6% reduction).
- And finally to 0.0562 kg/min with the post-additive diesel (a 12.5% reduction relative to the baseline).

This progressive improvement may be explained by the reduction of carbon deposits on internal engine components (cleaning effect) and/or by a combustion chamber conditioning effect. In the latter case, the graphene oxide additive may create a nanocoating that acts as a dry lubricant, improving fuel atomization and heat transfer characteristics that persist beyond the treatment window.

This trajectory directly mirrors the NOx behavior observed in Figure 4, where the post-additive diesel also maintained emissions lower than the pre-additive baseline. This reinforces the interpretation that the additive induces lasting modifications to the combustion environment, rather than acting solely as a fuel-borne additive during its active treatment period.

Together with the 91.1% reduction in opacity (Section 4) and the 0.57% increase in HHV (Section 3.1), the fuel consumption data complete a consistent picture: the graphene oxide additive promotes more complete combustion, extracting more useful energy from each kilogram of fuel while simultaneously reducing all key indicators of incomplete combustion: particulate opacity, NOx formation, and fuel mass consumed per unit time.

6. Carbon Monoxide and Oxygen Analysis in Exhaust Gases

6.1 Measurement Conditions

CO and O_2 concentrations in the exhaust gases were determined using the Bacharach analyzer, the same equipment used for NOx measurements, under standardized engine operating conditions at 70 °C and 1800 rpm. The same sequential before/during/after protocol was applied, with steady-state values recorded for each phase of the test (Fig. 6).

6.2 Results and Technical Interpretation

Diesel fuel alone showed a CO range of 803–844 ppm (average 828 ppm) with an O_2 content of 13.8%. The incorporation of GO additive at 8 ppm raised CO to a range of 870–1005 ppm (average 957 ppm), equivalent to a +15.6% increase, while O_2 increased to 14.7% (+6.9%). In the post-enhancement phase, CO averaged 931 ppm (+12.4%) and O_2 reached 14.9% (+8.1%). The persistence of these values in the post-treatment run is consistent with the residual conditioning effect observed in the NOx and fuel consumption measurements.

The simultaneous increase in CO and O_2 suggests a modification of the combustion thermal profile induced by the additive, which cannot be attributed to mixture enrichment or depletion. This behavior is amenable to optimization by adjusting the additive concentration, so that the trade-off between carbon oxidation and oxygen availability can be balanced to mitigate CO emissions without penalizing combustion efficiency.

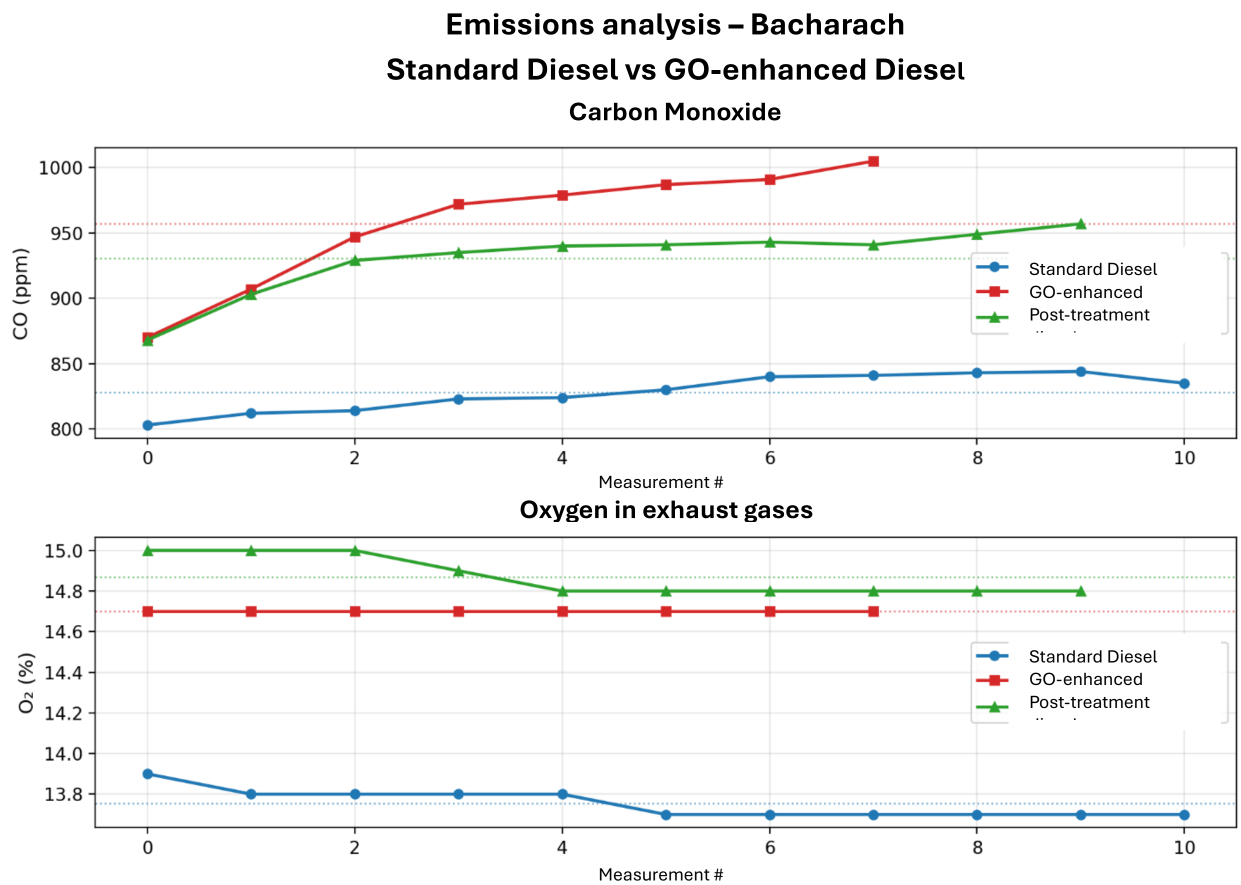


Figure 6. CO and O_2 emission analysis in exhaust gases.

7. Conclusions

Following the comprehensive analysis of commercial diesel enhanced with the graphene oxide-based additive and the emissions evaluation on a FAW diesel engine under a before/during/after protocol, the following conclusions are established:

- **Energy Optimization: A 0.57% increase in Higher Heating Value was validated, reaching 45.76 MJ/kg. This result is technologically significant given that the base fuel (45.50 MJ/kg) was already near the standard theoretical upper limit, demonstrating graphene's capacity to improve the energy density of the system.**

- **Superior Thermal Stability: TGA tests, conducted at 30 °C/min under N_2 for both samples, revealed that the GO-Enhanced sample retains appreciable mass up to 317 °C, compared to 265 °C for the fossil diesel reference, representing a 52 °C extension in the complete degradation temperature (<2% residual mass). The DTG Tmax of the fossil diesel (231.3 °C) shifts to 146.0 °C in the GO-Enhanced sample, an effect attributable to the volatilization of the carrier vehicle (hexanes) between 100 and 160 °C.**

- **Thermochemical Profile: Heat flow analysis (DSC) identified endothermic behavior in the GO-Enhanced sample up to approximately 190 °C, attributed to the volatilization of the carrier vehicle. The exothermic peak shifted from 297.7 °C (fossil diesel) to 382.8 °C (GO-Enhanced sample), with a reduction in peak heat flow from 2.097 to 1.677 W/g, indicating a more gradual and temperature-distributed energy release.**
- **Functional Group Identification: The FT-IR spectrum confirmed the presence of the biodiesel carbonyl group at 1750 cm^{-1}, which acts as a graphene stabilization vehicle without altering the chemical signature of the dominant hydrocarbon matrix.**
- **Physical Properties and Regulatory Compliance: Density (0.8227 g/cm^3) remained practically unchanged relative to the control (0.8226 g/cm^3), and the increase in kinematic viscosity at 40 °C was negligible, confirming full compatibility with conventional injection systems.**
- **Opacity Reduction: Opacimeter measurements confirmed a 91.1% reduction in exhaust opacity (from 17.90% to 1.59%) and a 91.3% reduction in the extinction coefficient K (from 0.460 to 0.040 m^{-1}), validating the additive as an effective solution for reducing visible particulate emissions.**
- **NOx Reduction: Additive treatment produced a sustained reduction of approximately 33% in NOx emissions (from ~325 ppm to ~215 ppm). Additionally, a persistent engine conditioning effect was observed, maintaining post-additive diesel NOx levels significantly below the pre-treatment baseline.**
- **Fuel Efficiency: Gravimetric fuel consumption showed a progressive reduction throughout the test protocol; the post-additive diesel achieved a 12.5% reduction in consumption rate relative to the baseline, consistent with the conditioning effect observed in the emissions measurements.**

8. Evaluator's Notes

The results obtained show that the addition of a graphene-based additive at a final concentration of 8 ppm in fossil diesel preserves the critical physicochemical properties of the fuel and is associated with measurable improvements in key engine performance indicators. In particular, modest increases in heating value, greater thermal stability, a very marked reduction in opacity, decreased NOx, and lower fuel consumption rate were documented under the tested protocol.

Within the scope of this validation, the evaluated system may be considered technically viable as an alternative for improving diesel combustion, with potential benefits in visible emissions and operational efficiency. Given that the concentrated formulation was prepared and supplied by the applicant and that the evaluation was conducted at a single concentration of 8 ppm, the results should be interpreted as a technical performance validation under a specific operating condition, subject to further optimization.

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