

Assessment of Air Pollutant Emissions from Combustion of Refined Petroleum Fuels and Their Environmental Implications

Ismail Abiodun Jeje¹, Ismail E. Muhibbu-Din^{2*}, Ismaila A Oyehan¹, and Jacob Ademola Sonibare¹

¹Chemical Engineering Department, Obafemi Awolowo University, Osun State, Nigeria

²Chemical Engineering Department University of Ilorin, Kwara State, Nigeria

Abstract

Air quality deterioration cannot be dissociated from the wide-spread domestic and industrial combustion of refined crude oil products for various uses. Nature of pollutants emitted during combustion is however estimated, to an extent, by the composition of hydrocarbon products. Yet, accurate measurement of emission parameters is essential to set some standard for quality control of indoor and outdoor air. Therefore, in this study, the combustion constituents of fifteen (15) types of fuels representing five from each of three refined products of petroleum, namely, petrol (PMS), kerosene (DPK) and diesel (AGO) were investigated in a fabricated combustion chamber. Emission characteristics of the fuels were measured using Air sampler E-850. Characterization of the polluted air showed hydrocarbons, CO and NO_x were the main constituents of the emission. It appears that only the combustion of AGO is environmentally sustainable based on standard set by the Federal Ministry of Environment of Nigeria for emission from stationary sources. Corresponding emission factors were obtained for PMS, DPK and AGO.

Keywords: Air Quality; Refined Petroleum Products; Combustion; Emission Factor.

1. Introduction

The economic and environmental consequences of fossil fuel combustion; particularly gasoline, kerosene, and diesel have been extensively documented. These fuels remain key sources of energy for domestic, industrial, and power-generation purposes. Chemically, they consist mainly of carbon and hydrogen, producing carbon dioxide and water as primary combustion products. However, incomplete combustion generates additional pollutants such as carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter, which degrade ambient air quality and contribute to climate change and adverse health outcomes. According to [1] the key criteria air pollutants generated during combustion include particulate matter of different sizes (PM₁₀, PM_{2.5}), volatile organic compounds (VOCs), nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), ammonia (NH₃), and ozone. In Nigeria, fuel combustion exhausts are a major contributor to elevated ground-level ozone concentrations [2].

The quantity and composition of pollutants released depend on several factors, including fuel grade, engine size, vehicle model, fuel type and delivery system, catalytic converter efficiency, vehicle maintenance practices, road conditions, and even the country of origin of the vehicle [3]. In Cairo, vehicle emissions from gasoline combustion have been reported to release carbon dioxide (CO₂), hydrocarbons (HC), nitrogen oxides (NO_x), and carbon monoxide (CO) as the predominant pollutants [3]. The accumulation of atmospheric CO₂ has long been recognized, with its environmental implications first highlighted in the pioneering work of Arrhenius [4].

*Corresponding author E-mail: muhibbudin.ei@unilorin.edu.ng

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In recent decades, concerns regarding the role of CO₂ as a major driver of environmental hazards have intensified. In many developing countries, rising demand for fossil fuels to meet economic growth and energy needs has further accelerated CO₂ emissions, underscoring the urgent need for targeted mitigation strategies. Numerous studies have shown that fuel combustion in automobiles is a significant source of greenhouse gases (GHGs), which not only contribute to global warming but also pose serious risks to human health and ecological systems. The contribution of fossil fuel combustion to greenhouse gas (GHG) accumulation in the atmosphere has been widely established in the literature. Numerous studies confirm that emissions from gasoline, diesel, and other petroleum products are among the largest anthropogenic sources of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), all of which are primary drivers of climate change [5,6].

Recent analyses show that fossil fuel emissions continue to rise despite global mitigation efforts, with average annual growth of approximately 1% over the past decade [5, 7]. While historical studies highlighted differences in the geographical distribution of biomass burning and fossil fuel combustion, current data suggest that fossil fuel use is now the dominant contributor to global GHG concentrations [8, 9]. This underscores the urgent need to integrate spatially resolved emission inventories into climate policy and energy planning. Air pollution from fossil fuel combustion has been strongly associated with increased mortality from respiratory and cardiovascular diseases, including asthma, chronic obstructive pulmonary disease (COPD), and atherosclerosis [10, 11].

To mitigate these adverse health effects, governments have enacted environmental laws and regulations. In the United States, the Clean Air Act established stringent limits on emissions, while in Nigeria the Federal Environmental Protection Agency (FEPA) created in 1988 to address growing concerns about air quality [12, 13]. Despite these frameworks, limited locally derived emission factors exist for petroleum products from indigenous refineries, making it imperative to develop context-specific data that can support regulatory standards and environmental policy.

2. Materials and Method:

2.1. Collection of Samples

Samples of petrol (PMS), kerosene (DPK), and diesel (AGO) were obtained from the sampling unit of an indigenous refinery and stored under appropriate conditions prior to use. The identity of the products was confirmed based on their characteristic properties, including colour, odour, boiling point, and density.

2.2. Procedure of Experiment

Emission characterization was performed using a combustion analyser (E-850), a fabricated combustion chamber, and a Clarke's air compressor to ensure sufficient airflow. A combustion analyser (E-850) is a portable, industrial-grade instrument used to measure and evaluate the composition of flue gases and emissions from combustion processes such as boilers, furnaces, burners, engines, and turbines. The experimental protocol was designed following general guidelines for stationary combustion source testing (ASTM D6522-11; ISO 12039:2019).

Variable volumes (10, 20, 30, 40, and 50 mL) of each fuel sample (petrol, kerosene, and diesel) were measured using a Class A graduated cylinder in accordance with ASTM E287-02. Each

measured volume was introduced into the combustion chamber and ignited under controlled conditions.

The analyser probe was positioned at the chamber outlet, consistent with flue gas sampling procedures outlined in ISO 12039:2019, to measure the concentration of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x). For accuracy and reproducibility, each experimental run was performed in triplicate, and mean values were calculated for subsequent analysis.

Table 1: Dimensions of fabricated combustion chamber.

Combustion Chamber parts	Specifications (cm)
Outer chamber height	20.0
Inner chamber height	5.00
Base plate height	3.00
Outer chamber diameter	43.50
Inner chamber diameter	22.50
Base plate diameter	32.85
Pipe diameter	5.40

Table 2: Stationary source emission limits data [19].

Pollutant	Limits (mg/m ³)
CO	10 .0
HC	50.0
NO _x	350 .0– 1000 .0
SO ₂	30.0 – 3000.0

2.3 Estimations of Emission Factors

The estimation of emission factors for gaseous pollutants was derived from three primary parameters: pollutant concentration in the flue gas, the mass of fuel consumed, and the combustion time. Emission factors (EF) were calculated following established methodologies for stationary source emissions, as outlined in recent guidelines by the Intergovernmental Panel on Climate Change [14] and the European Environment Agency [15].

Two governing equations were applied for the determination of emission factors, while a third equation was used to estimate the emission rate of individual pollutants.

Equation (1) was used for emission factor calculations and this was based on mass consumed (g/kg) were stated below;

$$n = Cp \times V \quad (1)$$

$$Emission\ factor = \frac{mass\ of\ emitted\ pollutant(g)}{mass\ of\ fuel\ combusted\ (kg)} = \frac{n}{M} \quad (2)$$

Calculation of emission rate (ER) base on time:

$$Emission\ rate = \frac{mass\ of\ emitted\ pollutant(g)}{run\ time\ for\ combustion\ process(s)} = \frac{n}{t} \quad (3)$$

The mass of emission pollutants is being represented by n in gram,

C_p is the concentration of measured gaseous pollutants in mg/m³,

V is volume combusted in m³,

M is the mass of combusted fuel in kilograms, and

t is the combustion runtime in seconds.

2.4 Measurement of Air Quality Implication

The concentrations of gaseous pollutants obtained from the combustion experiments were compared with regulatory limits set by the Federal Ministry of Environment (FMEnv), formerly known as the Federal Environmental Protection Agency (FEPA). Table 3 presents the average measured concentrations of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) alongside the FMEnv standards. This comparison was used to assess the level of compliance of the fuels with national air quality guidelines. Such evaluation provides insight into the adequacy of safety margins required for public health protection, informs prioritization of emission control strategies, and establishes a benchmark for assessing air quality at both local and national levels.

Figure 1 illustrates the experimental setup employed in this study, including the fabricated combustion chamber, combustion analyser, and associated equipment used for emission measurements.



Figure 1: Experimental setup showing the fabricated combustion chamber and the E8500 emission analyser used for pollutant measurement.

3. Results and Discussion

The refined petroleum products were first identified and characterized, after which emission factors for the major gaseous pollutants were calculated. The air quality implications of these emissions were then evaluated by comparing the measured concentrations with standard values reported in the literature and regulatory guidelines. Based on these findings, appropriate control measures were subsequently discussed.

3.1 Refined Petroleum Products Emission Characterization

This section presents the emission concentrations of gases and the combustion duration of the refined petroleum products. The pollutants characterized in this study included carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x), which are of particular concern due to their significant impact on air quality and human health.

3.2 Average Measured Levels of Air Pollutants from PMS

Table 3 summarizes the average concentrations of gaseous emissions measured during the combustion of Petrol Motor Spirit (PMS). The measured average concentrations of air pollutants for PMS over the period of time for each volume combusted are presented in Table 3.

Table 3: Emission Characterization of PMS Combustion at Varying Volumes.

Vol. of PMS(ml)	Time(s)	HC(mg/m ³)	CO (mg/m ³)	NO _x (mg/m ³)
10	128.8	45.742	85.00	0
20	182.0	56.634	15.33	0
30	230.2	59.901	50.33	632.00
40	318.6	2637.838	52.67	455.33
50	384.6	56.634	50.67	588.67

3.3 Average Measured Concentrations of Air Pollutants from DPK Combustion

Table 4 presents the average measured concentrations of gaseous emissions produced during the combustion of Dual-Purpose Kerosene (DPK). The measured average concentrations of air pollutants for DPK over the period of time for each volume combusted.

Table 4: Emission Characterization of DPK Combustion at Varying Volumes.

Vol. of DPK(ml)	Time(s)	HC(mg/m ³)	CO (mg/m ³)	NO _x (mg/m ³)
10	228.2	67.525	0	0
20	436.4	91.485	19	583.33
30	607.4	200.397	5.33	333.00
40	739.6	119.802	12.667	734.33
50	924.8	130.693	54.667	209.00

3.4 AGO Average Measured Concentration of Air Pollutants

The average concentrations of gaseous emissions generated during the combustion of Automotive Gas Oil (AGO) are presented in Table 5. The measured average concentrations of air pollutants for AGO over the period of time for each volume combusted.

Table 5: AGO Emission Characterization of Combustion of Varying Volumes.

Vol. of PMS(ml)	Time(s)	HC(mg/m ³)	CO (mg/m ³)	NO _x (mg/m ³)
10	118.2	15.247	25.667	139.667
20	396	24.614	0	159.333
30	717.8	33.637	47	248
40	1096	42.764	0	706.667
50	1401.8	41.386	0	720

3.5 PMS Emission Factors of Air Pollutants

Emission factors, calculated on a mass basis for each gaseous pollutant emitted during the combustion of Premium Motor Spirit (PMS) are presented in Table 6.

Table 6: PMS Emission Factors for Concentrations of Air Pollutants from the Varied Masses.

		Masses of fuel consumed (10 ⁻³ L)				
		10	20	30	40	50
PMS	HC	6.36E-05	7.87E-05	8.32E-05	3.665E-03	7.87E-05
	CO	1.68E-04	2.13E-05	6.99E-05	7.32E-05	7.04E-05
	NO	0	0	8.781E-04	6.33E-04	8.18E-04

3.6 DPK Emission Factors of Air Pollutants

Table 7 presents the emission factors, calculated on a mass basis, for each gaseous pollutant emitted during the combustion of Dual-Purpose Kerosene (DPK).

Table 7: DPK Emission Factors for Concentrations of Air Pollutants from the Varied Masses.

		Masses of fuel consumed (10^{-3} L)				
		10	20	30	40	50
DPK	HC	8.34E-05	1.13E-04	2.47E-04	1.48E-04	1.61E-04
	CO	2.88E-04	2.35E-05	6.584E-06	1.56E-05	6.75E-05
	NO	0	7.2E-04	4.111E-04	9.07E-04	2.58E-04

3.6 AGO Emission factors of air pollutants

Table 8 presents the mass-based emission factors for each gaseous pollutant generated during the combustion of Automotive Gas Oil (AGO).

Table 8: AGO Emission Factors for Concentrations of Air Pollutants from the Varied Masses.

		Masses of fuel consumed (10^{-3} L)				
		10	20	30	40	50
AGO	HC	1.83E-05	2.96E-05	4.0429E-05	5.14E-05	4.97E-05
	CO	3.08E-05	0	5.649E-05	0	0
	NO	1.68E-04	1.92E-04	2.98E-04	8.49E-04	8.65E-04

This study investigated the emissions of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) from the combustion of refined petroleum products (PMS, DPK, and AGO). Results showed that HC emissions increased with rising ambient air temperature and combustion temperature. Key parameters influencing HC emissions included combustion chamber design, temperature, pressure, and the residence time of fuel within the chamber. These observations are consistent with earlier findings reported by [20]. Furthermore, the absence of a visible blue flame during combustion suggests that CO was rapidly oxidized to CO_2 in the presence of sufficient oxygen at elevated temperatures, which aligns with the findings of [16].

The measured concentrations of CO, HC, and NO_x from the combustion of petrol (PMS), kerosene (DPK), and diesel (AGO) are presented in Table 3 – Table 5. The results indicate clear variations in emission profiles among the three fuel types. Petrol combustion produced the highest levels of hydrocarbons, whereas kerosene exhibited comparatively elevated carbon monoxide emissions. Although diesel was generating lower hydrocarbon and CO levels, it showed significant NO_x emissions, consistent with its higher combustion temperature. When compared with the Federal Ministry of Environment (FMEnv) regulatory standards, only diesel combustion demonstrated partial compliance, particularly with respect to CO and HC emissions, although its NO_x concentrations frequently exceeded permissible limits. These findings suggest that the type of refined fuel strongly influences the pollutant profile and, consequently, the potential risks to air quality and public health.

The variations in fuel volumes burned were found to influence the emissions of nitrogen oxides (NO_x), particularly nitric oxide (NO) and nitrogen dioxide (NO_2). These emissions originated from three primary sources: fuel-bound nitrogen, nitrogen present in the combustion air supplied by the compressor, and thermal NO_x generated at high combustion temperatures. The study

revealed that both combustion chamber temperature and ambient air conditions significantly contributed to NO_x formation. Notably, NO_x formation increases significantly when combustion temperatures exceed approximately 1300 °C, primarily due to the oxidation of atmospheric nitrogen through the thermal (Zeldovich) mechanism. This trend is consistent with the combustion temperatures recorded in this study and aligns with findings from recent combustion studies [17,18].

The emissions from PMS combustion at varying volumes (10–50 ml) are presented in Table 3 and compared against the stationary source emission limits established by the Federal Ministry of Environment [19]. Hydrocarbon (HC) and carbon monoxide (CO) concentrations exceeded the permissible limits at all volumes, except for HC at 10 ml, which remained below the standard threshold. Nitrogen oxides (NO_x) were within the allowable limits at 10–20 ml but approached the upper limit at 30–50 ml. Overall; the results indicate that PMS combustion generally exceeds FMEnv emission standards, with the exception of certain NO_x emissions at lower fuel volumes. This suggests that PMS from indigenous refineries may be utilized as an energy source but with considerable environmental implications, particularly due to its elevated HC and CO emissions.

The emissions from DPK combustion at variable volumes (10–50 ml) are summarized in Table 4 and compared with stationary source emission standards (FMEnv, 1991). Hydrocarbon (HC) and carbon monoxide (CO) concentrations exceeded the permissible limits at most volumes, with the exception of CO at 10 ml and 30 ml, which remained within the standard. In contrast, nitrogen oxides (NO_x) from DPK combustion were consistently below the regulatory limits. Overall, the findings suggest that while DPK combustion contributes to elevated HC and CO emissions, NO_x levels remain compliant. Thus, DPK from indigenous refineries could serve as an energy source with relatively limited environmental impacts, provided proper measures are implemented to control HC and CO emissions.

The emissions from AGO combustion at variable volumes (10–50 ml) are presented in Table 5 and compared with stationary source emission standards [18]. Both hydrocarbon (HC) and nitrogen oxides (NO_x) concentrations were consistently below the permissible limits across all test volumes. Carbon monoxide (CO) emissions also complied with the standard, except at 10 ml and 30 ml, where slight exceedances were observed. Overall, AGO combustion demonstrated a high level of compliance with FMEnv standards, indicating its potential as a relatively sustainable energy source. Nevertheless, the occasional CO exceedances highlight the need for monitoring and proper combustion control to minimize environmental impacts.

4. Conclusions

This study identified and characterized emissions associated with the combustion of refined petroleum products (petrol, kerosene, and diesel) sourced from an indigenous refinery, using a fabricated combustion chamber. The principal pollutants detected were hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x), measured with the aid of a gas combustion analyzer. These emissions were released into the surrounding environment, with potential adverse impacts on local air quality. Emission factors for the pollutants were determined, and comparison with established standards revealed that while some emissions were within permissible limits, others exceeded them.

The findings indicate that although these refined products can serve as energy sources, their combustion poses notable environmental risks, particularly from elevated HC and CO emissions. This underscores the need for stricter regulatory oversight, improved combustion efficiency, and the development of policies aimed at reducing pollutant release to safeguard air quality.

Given the limitations of the present study, future research should focus on comparative investigations of air-fuel ratios, determination of optimum combustion conditions, and advanced control strategies to minimize emissions. Such efforts will provide deeper insights into achieving sustainable fuel utilization while mitigating environmental impacts.

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