ESTIMATION OF EMISSION FACTOR FROM THE COMBUSTION OF AGO, PMS AND DPK FROM THE KADUNA REFINERY AND PETROLEUM COMPANY IN NIGERIA

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ABSTRACT: *Air emissions from the combustion of AGO, PMS and DPK were characterized for gaseous air pollutants using an E8500 combustion gas analyzer. The measured concentrations were used to calculate the emission factors of the pollutants. The emission factors for the gaseous emission from AGO were for 10 ml of AGO, HC was 4.584E-05 g/l, CO was 1.633E-05 g/l, NO_x was 0.00021 g/l, and zero values were recorded for both CO_2 and SO_2; for 50 ml of AGO, HC was 0.000142 g/l, NO_x was 0.001516 g/l and zero values were recorded for both CO, CO_2 and SO_2. From PMS were for 10 ml of PMS, HC was 6.9846E-05 g/l, CO was 0.00017 g/l, NO_x was 0.00034 g/l, and zero values were recorded for both CO_2 and SO_2; for 50 ml of PMS, HC was 8.731E-05 g/l, CO was 0.000213 g/l, NO_x was 0.0008 g/l, SO_2 was 3.76E-06 g/l and CO_2 was 0.0066 g/l. From DPK were for 10 ml of DPK, HC was 3.4923E-05 g/l, CO was 2.1667E-05 g/l, NO_x was 0.000089 g/l, and zero values were recorded for both CO_2 and SO_2; for 50 ml of DPK, HC was 6.1115E-05 g/l, CO was 4.0667E-05 g/l, NO_x was 0.000191 g/l and SO_2 was 2.667E-06 g/l. This study shows that For 10 ml, DPK had the minimum emission factor for HC, AGO had the minimum emission factor for CO, DPK had the minimum emission factor for NO_x. For 50 ml, AGO had the minimum emission factor for CO, SO_2, DPK had the minimum emission factor for HC, NO_x. Therefore, AGO and DPK can act as a source of fuel with the best sustainable environmental effects.*

Keywords: Refinery; Emissions; Concentration; Pollutants; Petroleum

1. AIM AND BACKGROUND

Air pollution can be seen as a major threat to human health and the ecosystem. It can be portrayed as the contamination of the environment by solids, liquids or gaseous pollutants that is detrimental to humans, plants, and animals, or produce repugnant odor (USEPA, 1994). Air pollution is a major environmental challenge plaguing many underdeveloped countries that needs addressing (Kanada, *et al*., 2013).
Furthermore, Adamu and Wubeshet (2006) defined air pollution as any atmospheric condition where harmful agents are seen in high concentrations in which they pose serious health issues on humans and the environment. Air pollutants affect our health in diverse ways ranging from nausea to death (Dickey, 2000).

They are emitted into the atmosphere from nature and from various human and non-human activities that create pollution all over the world. Air pollutant emissions come from both natural and anthropogenic sources.

Pooley and Miller (1999) suggested that evaporation of seawater, volcanic eruptions and forest fires and airborne particulate matter are all-natural sources of air pollution. These natural sources of air pollution are further classified into biogenic and geogenic emissions. Geogenic emissions occur from the emissions by the non-living world including volcanic emissions, natural fires and sea-salt emissions while biogenic emissions are emissions emitted from the living world including VOC emissions from forests and CH_4 emissions from swamps (Daly and Zanenetti, 2007).
Anthropogenic sources of air pollution include activities from the use of combustion engines (vehicles), industrial machinery and power plants such as the use of internal combustion engines (automobiles). These activities are carried out on an industrial scale, hence, it is considered as the major source of air pollution, with vehicular transport responsible for about 80% of the present air pollution in the world (Möller *et al.*, 1994). Fenger, (1999) suggested that around the world, and particularly for CO, NOx and HC, road traffic is the dominant anthropogenic source of pollution in urban areas.

The population and the environment are exposed to these pollutants produced by natural and/or anthropogenic sources and also from complex atmospheric chemical reactions. These pollutants are of two physical forms, the first is a gaseous form which includes SO_2, O_3 and hydrocarbon vapors, among others while the second is in the form of particulate matter including dust, smoke, mists and fly ash.
This study investigate the emission factor of refined petroleum products (PMS, AGO and DPK) from Kaduna Refinery and Petroleum Company.

2. METHODOLOGY

Fuel samples – gasoline, kerosene, and diesel; measuring cylinder; a conical flask; a combustion chamber; an air compressor; a combustion analyzer are the materials and equipment that was used during this study. Figure 1 shows the study area.

Figure 1. Kaduna Refining and Petroleum Company

2.1. Combustion apparatus, fuel, and experimental procedure

The E8500 plus combustion analyzer (Figure 2) was used for gaseous emission characterization. It is the most powerful and advanced portable emissions analyzer on the market and is a complete, portable tool for EPA compliance–level emissions monitoring of boilers, engines, and other combustion equipment. It has up to nine gas sensors with a weight of 5 kg and a dimension of 26 x 15 x 24 cm.

It is an analyzer equipped with an inbuilt thermoelectric chiller that efficiently and quickly removes water vapor from gas samples to prevent gases from bubbling into the condensate drain gas velocity measurement capability which makes the instrument scientifically efficient. Gaseous emissions from the combustion of refined petroleum products were measured using the E8500 plus portable industrial gas and emissions analyzer. The combustion analyzer is capable of measuring gaseous emissions including; Oxygen (O_2), Hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), Oxides of Nitrogen NO_x (NO, NO_2), Sulphur dioxide (SO_2), and Hydrogen Sulphide (H_2S). Its CO detection range is 0 - 2000 ppm with 1 ppm resolution while its NO and NO_2 detection range is 0 - 400 ppm with 1 ppm resolution. The detection range of its H_2S is 0 - 500 ppm with 1 ppm resolution. In addition, the temperature of the flue gas and the ambient air in its area of operation can also be measured with the analyzer at the range of 0 - 1000 ^{o} C. It also measures pressure/draft excess air of combustion, gas velocity, and the efficiency of combustion

The air compressor used is a 50-liter air receiver which has a 3 HP, 230 V, 1 HP motor with electrical overload protection. This 66 kg robust air compressor of 930 x 420 x 800 mm dimensions features a heavy-duty cast iron pump, designed to appeal to commercial, agricultural, and consumer users. It delivers a more-than-adequate volume & pressure of compressed air. It has also a maximum working pressure of 10.3 bar (148.5 psi) controlled by a fully automatic pressure switch. It has a cast-iron `V` type twin cylinder air

compressor pump with 15cfm displacement. The air compressor is powered by a petrol-fuelled engine that is placed far away from the combustion chamber and analyzer so that it does not influence the emissions being read by the analyzer. It is capable of providing a more than adequate volume and pressure of compressed air to power professional spray-guns and many of the frequently used air tools.

Without the gas sampling probe connected to the instrument, the combustion analyzer is turned on. Baseline calibration is required to zero out any sensors that may have drifted far from zero. After the required baseline calibration and there were no errors, the gas sampling probe is connected to the instrument. The electronic analyzer is now ready for use to monitor any gaseous emission for which the appropriate sensor is installed. Gaseous emissions including; Hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), Oxides of Nitrogen (NO, NO_2, NO_x), Sulphur dioxide (SO_2), and Hydrogen Sulphide (H_2S) were measured with the use of the combustion analyzer. All emissions were measured in mg/m^3 with the exception of HC and CO which was measured in ppm and % respectively.

Fuel samples were stored in air-tight plastic containers to avoid contamination and maintain sample quality. The fuel containers were leak-proof to prevent the escape of gases including hydrocarbon. The fuel samples stored include PMS, DPK and AGO from KRPC. The volume of refined products was varied between 10 ml and 50 ml. This was done to determine the time taken for each volume to be combusted and the characterization of the air pollutants. Also, to determine the emission rate of the gaseous pollutant which is the unit mass of gaseous emissions per time taken for characterization of the air pollutants from the combustion of KRPC refined petroleum products. For each experimental run, a varied volume of refined products was measured with a measuring cylinder.

To determine the emission factors of the gaseous air pollutants from the combustion of KRPC refined petroleum products, parameters including the concentration of the air pollutants, the mass of fuel consumed and time is taken for combustion were recorded.

Equations 1 and 2 were employed in calculating the emission factors of the air pollutants in the emission, Emission factors on the basis of mass (g/L) were calculated using;

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

$$EF = \frac{mass\ of\ emitted\ pollutants\ (g)}{volume\ of\ fuel\ combusted\ (L)} = \frac{n}{M} \quad (2)$$

Where;

n is the mass of emitted pollutants in *grams*

Cp is the concentration of measured gaseous pollutants in *mg/m^3*

V is the volume of fuel consumed in the combustion process in m^3

M is the volume of fuel combusted in *liters*

Figure 2. E8500 Industrial Combustion Gas Analyzer

2.2 Sampling and measurement techniques

Air was passed into the combustion chamber with the aid of a Clarke air CE compressor (Figure 3) to provide sufficient air for the combustion process. The air supplied was at a constant flowrate which was achieved at the maximum working pressure condition of the compressor, 10.3 bar (148.5 psi). The air compressor was powered by a petrol-fuelled engine which was placed far away from the combustion chamber and analyzer so that the compressor emissions do not interfere with the emissions being read by the analyzer.

For each experimental run, the measured volume sample of each DPK was transferred into the combustion chamber, air from the compressor was passed into the chamber and ignition was done via the ignition hole using a lightning gun. The lid was placed firmly on it as combustion commences. During the combustion process, gaseous emissions including; Hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), Oxides of Nitrogen (NO, NO_2, NO_x), Sulphur dioxide (SO_2), and Hydrogen Sulphide (H_2S) were emitted into the atmosphere from the combustion chamber stack and into the atmosphere. The combustion analyzer gas probe was inserted into the combustion zone through the stack of the chamber in order to measure the accurate air pollutants coming directly from the combustion zone in the chamber as opposed to the ambient zone when measured from the top of the combustion chamber.

Readings were taken and recorded with the use of the combustion analyzer as the concentration values of air pollutants changed during the period of combustion. At the end of combustion, the combustion analyzer was calibrated back to zero in order to zero out the sensors that may have drifted far from zero. Three experimental runs were carried out for each volume of refined products that were varied.

Plate 3. Clarke Air CE Compressor

3. RESULTS AND DISCUSSION
3.1 Calculated emission factors of air pollutants for AGO

As presented in Table 1, the Emission Factors for 10 ml of AGO, HC was 4.584E-05 g/l, CO was 1.633E-05 g/l, NO_x was 0.00021 g/l, and zero values were recorded for both CO_2 and SO_2.
The Emission Factors for 20 ml of AGO, HC was 7.64E-05 g/l, CO was 4.433E-05 g/l, NO_x was 0.000689 g/l, and zero values were recorded for both CO_2 and SO_2.
The Emission Factors for 30 ml of AGO, HC was 0.000102 g/l, NO_x was 0.000692 g/l, and zero values were recorded for both CO, CO_2 and SO_2.

Table 1. Emission Factors of Gaseous Emissions from AGO Combustion

Vol of DPK	Emission Factor (g/l)				
	HC	CO	NO_x	SO_2	CO_2
10 ml	4.584E-05	1.6333E-05	0.000206	0	0
20 ml	7.64E-05	4.433E-05	0.000689	0	0
30 ml	0.000102	0	0.000692	0	0
40 ml	0.000155	0	0.001459	0	0
50 ml	0.000142	0	0.001516	0	0

The Emission Factors for 40 ml of AGO, HC was 0.000155 g/l, NO_x was 0.001459 g/l, and zero values were recorded for both CO, CO_2 and SO_2. The Emission Factors for 50 ml of AGO, HC was 0.000142 g/l, NO_x was 0.001516 g/l and zero values were recorded for both CO, CO_2 and SO_2.
Combustion of 20 ml AGO had the maximum emission factor of all gaseous emission except for NOx. The minimum emission factor for HC was obtained at 30 ml while the minimum emission factor CO and NOx was obtained at 10 ml. The maximum emission factor for NOx was obtained at 50 ml.

3.2 Calculated emission factors of air pollutants for PMS

As presented in Table 2, the Emission Factors for 10 ml of PMS, HC was 6.9846E-05 g/l, CO was 0.00017 g/l, NO_x was 0.00034 g/l, and zero values were recorded for both CO_2 and SO_2.

The Emission Factors for 20 ml of PMS, HC was 5.8933E-05 g/l, CO was 0.00013 g/l, NO_x was 0.000784 g/l, and zero values were recorded for both CO_2 and SO_2. The Emission Factors for 30 ml of PMS, HC was 5.02018E-05 g/l, CO was 0.000084 g/l, NO_x was 0.00798 g/l, SO_2 was 0.000004 g/l and zero value was recorded for CO_2. The Emission Factors for 40 ml of PMS, HC was 6.5481E-05 g/l, CO was 0.00016 g/l, NO_x was 0.00085 g/l, SO_2 was 0.000003 g/l and CO_2 was 0.003 g/l. The Emission Factors for 50 ml of PMS, HC was 8.731E-05 g/l, CO was 0.000213 g/l, NO_x was 0.0008 g/l, SO_2 was 3.76E-06 g/l and CO_2 was 0.0066 g/l.

The combustion of 50 ml PMS had the maximum emission factor of all gaseous emission. Minimum emission factor for HC and CO was obtained at the combustion of 30 ml of PMS while minimum emission factor for SO_2 was observed at 20 ml and the minimum emission factor for NOx was observed at 40 ml.

Table 2. Emission Factors of Gaseous Emissions from PMS Combustion

Vol of PMS	Emission Factor (g/l)				
	HC	CO	NO_x	SO_2	CO_2
10 ml	6.98E-05	0.000117	0.00034	0	0
20 ml	5.89E-05	0.00013	0.00078	0	0
30 ml	5.02E-05	0.000084	0.00798	0.000004	0
40 ml	6.55E-05	0.00016	0.00085	0.000003	0.003
50 ml	8.73E-05	0.000213	0.0008	3.67E-06	0.0066

3.3 Calculated emission factors of air pollutants for DPK

As presented in Table 3, the Emission Factors for 10 ml of DPK, HC was 3.4923E-05 g/l, CO was 2.1667E-05 g/l, NO_x was 0.000089 g/l, and zero values were recorded for both CO_2 and SO_2. The Emission Factors for 20 ml of DPK, HC was 4.1471E-05 g/l, CO was 3.3333E-05 g/l, NO_x was 0.000118 g/l, and zero values were recorded for both CO_2 and SO_2. The Emission Factors for 30 ml of DPK, HC was 5.285E-05 g/l, CO was 4.933E-05 g/l, NO_x was 0.000183 g/l, and zero values were recorded for both CO_2 and SO_2. The Emission Factors for 40 ml of DPK, HC was 5.0201E-05 g/l, CO was 3.3E-05 g/l, NO_x was 0.000189 g/l and SO_2 was 0.000003 g/l. The Emission Factors for 50 ml of DPK, HC was 6.1115E-05 g/l, CO was 4.0667E-05 g/l, NO_x was 0.000191 g/l and SO_2 was 2.667E-06 g/l.

Combustion of 50 ml DPK had the maximum emission factor of all gaseous emission except for CO. Minimum emission factor for all gaseous emission was obtained at the combustion of 10 ml. The maximum emission factor for CO was observed at 30 ml.

Table 3. Emission Factors of Gaseous Emissions from DPK Combustion

Vol of DPK	Emission Factor (g/l)				
	HC	CO	NO_x	SO_2	CO_2
10 ml	3.492E-05	2.167E-05	0.000089	0	0
20 ml	4.147E-05	3.333E-05	0.000118	0	0
30 ml	5.238E-05	4.933E-05	0.000183	0	0
40 ml	5.021E-05	3.3E-05	0.000189	0.000003	0.003
50 ml	6.112E-05	4.067E-05	0.000191	3.67E-06	2.667E-06

4. CONCLUSION

Refined Petroleum Products from Kaduna Refinery and Petroleum Company namely Premium motor spirit (PMS), Automotive gasoline oil (AGO), and Dual purpose kerosene (DPK) were characterized for gaseous pollutants and the emission factors were calculated from the measured concentration.

For all the refined products, when the emission concentration of CO and HC from their combustion is compared with FMEvn (1991) the concentration was above the standard set for stationary source while for NO_x and SO_2 the emissions were below the permissible limit for stationary source.

For 10 ml, DPK had the minimum emission factor for HC, AGO had the minimum emission factor for CO, DPK had the minimum emission factor for NO_x. For 20 ml, DPK had the minimum emission factor for HC, CO, and NO_x. For 30 ml, PMS had minimum emission factor for HC, AGO had the minimum emission factor for CO, DPK had the minimum emission factor for NO_x DPK and AGO had the minimum emission factor for SO_2. For 40 ml, AGO had the minimum emission factor for CO, SO_2, DPK had the minimum emission factor for HC, NO_x. For 50 ml, AGO had the minimum emission factor for CO, SO_2, DPK had the minimum emission factor for HC, NO_x. Therefore, AGO and DPK can act as a source of fuel with the best sustainable environmental effects

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