Comparative Assessment of Some Emitted Pollutants’ Concentrations from Selected Fossil Fuel-fired Generators

F.O. Anjorin††, S. A. Abashi§, F.B. Masok², I.M. Essen³

††Department of Physics, University of Jos, Plateau State-Nigeria
§Department of Physics, Plateau State University, Bokkos, Nigeria
³Department of Science Technology, Akwa Ibom State Polytechnic, Ikot Osuru, Ikot Ekpene, Nigeria

*Corresponding author: frankanj@yahoo.com

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Abstract Fossil fuel-fired generators, though viable alternative sources of energy are a veritable source of several environmental problems. Measurements of gaseous and particle air pollutants is a vital step in exposure assessment and epidemiological studies. In this study, in-situ measurement of some pollutants emitted from selected fossil fuel-fired generators with a wide range of installed capacities (0.9-250kVA), which are under more realistic conditions than the laboratory approach of chamber testing was undertaking using real-time active sampling weekly for one year (November, 2015-October, 2016). The study reveals that the emission rate of CO from 0.9kVA generator, 2.0kVA generator, 50kVA CAT generator, 50kVA Micano generator, 250 kVA generator and 100kVA Micano generator are 93.48 mg/s, 107.67 mg/s, 1.12 mg/s, 12.47 mg/s, 0.08 mg/s and 9.69 mg/s, respectively; Similarly, the emission rate of SO2 from the aforementioned generators are 0.99 mg/s, 1.08 mg/s, 0.07 mg/s, 2.27 mg/s, 0.11 mg/s and 0.93 mg/s, respectively. Furthermore, these generators also emit H2S at the rate of 0.64 mg/s, 0.51 mg/s, 017 mg/s, 1.79 mg/s, 0.15 mg/s and 0.92 mg/s, respectively. An insightful analysis of the sampled emission data suggests that emissions from most of the selected generators pose serious potential hazard to the public heath of their immediate neighbourhood.

Keywords: Fossil Fuel, generator, emission, pollutants, microenvironments

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1. Introduction

Fossil-based fuels such as diesel, gasoline, natural gas, and LPG, which are derivatives of crude oil, are generally used in internal combustion engines. The approximate elemental structure of an average crude oil consists of 84% carbon, 14% hydrogen, 1-3% sulfur, and less than 1% nitrogen, oxygen atoms, metals, and salts [1]. Crude oil consists of a wide range of hydrocarbon compounds consisting of alkanes, alkenes, naphthenes, and aromatics. These are very small molecular structures such as propane (C₃H₈) and butane (C₄H₁₀) but can also be composed of mixtures of various structures with very large molecules such as heavy oils and asphalt. Therefore, crude oil needs to be distilled to be used in internal combustion engines. However, the thermodynamic cycles determine the fuel types suitable for the different internal combustion engines. These engines using fossil fuels, coupled to electricity generators are commonly used to provide electricity in remote sites and stand-by (emergency) facilities. However, these fuels can be demonstrated in different properties with each other. For example, gasoline fuels should have a high ignition resistance, while diesel fuels should have well self-ignition [1].

In Nigeria, due to the epileptic and grossly inadequate energy supply, the deployment of fossil fuels to powered generators is inevitably used as alternative sources of energy; this is a common lot of most of the developing nations, with majority of Sub-Sahara Africa (SSA) countries at the forefront [2,3]. An estimated 1.6 billion people or about one-fourth of the world population have no access to electricity and must rely on other sources of energy for survival [4]. Of this, about 50% is located in South Asia (35 % in India alone), 32 % in Sub-Sahara Africa and 14% in East Asia (not including Asia) [4]. In fact, [5] estimated that less than 10 % of the national electricity demand can be met through the national power grid in Nigeria. Hence, most industrial and business establishments in Nigeria rely heavily on fossil fuels for their generators in generating power to augment this deficit. Only recently in Nigeria, there was a ban on the use of generators to curb the emission of these gaseous and solid particles as well as to reduce noise pollution. But due to persistence in epileptic power supply from the
nation’s major power plant, the ban was not largely complied with. Rather, this was accompanied by more proliferation of combustion generators.

Although viable alternative sources of energy, fossil fuel-fired generators are a veritable source of a several environmental problems. Emissions from fossil fuels combustion in generating set have been associated with environmental pollution which in turn has adverse effects on the physical and mental health of individual [6,7]. These problems are more in the urban settlements of Nigeria than the rural settlements. Reactions involving these compounds can further contribute to elevated levels of other compounds, such as ozone. Furthermore, any impurities in the fuel, for example sulfur and metals such as mercury, are also emitted, sometimes as a gas (e.g. SO₂) or as PM (e.g. fly ash, including metals such as selenium, vanadium, and nickel) or as both (e.g. mercury). However, the combustion process is complex, leading to a mixture of organic gases and PM that is just as complex, comprising species that were originally present in the fuel (e.g. benzene) and products of incomplete combustion. The relative abundance of the constituents depends on the fuel type and combustion conditions [8]. However, in Nigeria, despite the increase in the deployment of generators in meeting the energy demand and with the environmental hazards such deployment have brought to human and public health around them, there are few researches focused on investigating their environmental impacts.

Although in recent works, measurements of gaseous and particle air pollutants have been used for exposure assessment and epidemiological studies of several point sources, there are no comprehensive pollution data set published in literatures about these emissions and their epidemiological effects on people within their microenvironments. Hence, there is a need to ascertain the levels of emission of these pollutants from the commonly used generators in Nigeria. Data of emission characteristics from different generators fired by different fuel types is needful in evaluating their environmental impacts and for modeling purposes; this will aid better combustion chamber design by manufacturers and effective control of the exhaust flue so as to reduce these negative impacts. In order to understand the pollutants exposures associated with such incidents and their potential reduction, the emission characteristics of these generators need to be better characterized. To determine the emission characteristics of the respective portable generators, it is often preferable that in-situ measurement of the flue emissions, which are under more realistic conditions than the laboratory approach of chamber testing is undertaking.

In recent published works, [9] investigated the influence of pollutants released from the operations of diesel-powered generators on ambient air quality and public health in Abeokuta, Ogun State, Nigeria. They experimentally determined the concentrations of the pollutants (PM₁, PM₂, CO, NOₓ, CH₄ from 1 to 25 kVA) and utilized questionnaires to evaluate the health impacts of these pollutants on the residents of the study area. The result showed that PM₁, PM₂, CO, NOₓ, CH₄, CO₂, SOₓ and NO₂ were significantly higher than the maximum recommended values. In addition, the respondents reported ailments such as nasal congestion, fever, headache and cough as the effects of degraded air quality due to emissions from these generators which agreed with the works of [10,11] and [12]. Also, [13] investigated the ambient air implication of the mass utilization of generators at base transceiver stations across Nigeria by evaluating the quantities of pollutants released from these sources. The base transceiver stations of seven communication network operators were considered and fuel-based emission factor method subject to the generators’ installed capacity and fuel consumption rate was employed to calculate the amounts of CO, SO₂, TVOC, NOₓ, PAH, PM₁₀ and PM₂.₅ released from these generators. The result showed that emissions greater than the standard limits were observed in four states of Nigeria. Highest total emissions of 7.22×10³, 7.81×10³, 8.28×10³, 9.45×10³ and 9.54×10³ tons/year were recorded at Akwa Ibom, Katsina, Oyo, Kano and Lagos states, respectively.

However, not much has been done in evaluating comparative assessment of the diesel-fired generators and gasoline-fired generators that are used for several purposes in the Nigeria society. Although [14] had posited that estimation is the preferred method for creating emission inventories since direct measurement of diesel engine exhaust is often cost prohibitive, direct emission measurement of the selected pollutants still guarantees more accurate and reliable data. In recent years, several epidemiological studies have emerged showing several negative health effects associated with short-term and long-term exposure to air pollutants. But according to [15], data on human exposure to air pollutants occurring in ground-level outdoor environments within a few meters of point sources is anecdotal. This study seeks to carry out a comparative assessment of pollutants emitted from some selected fossil fuel powered generators; four diesel-powered generators and two gasoline-powered generators with a wide range of installed capacities (0.9-250kVA).

2. Material and Methods

2.1. Study Area

Jos is the capital of Plateau State in North Central Nigeria. The city is located at 9°56 N 8°53 E with an elevation of about 1238m. Jos is the most densely populated area in Plateau State, Nigeria. The study sites were selected around the busy and cosmopolitan areas of Jos North (see Figure 1). This Local Government Area play host to several educational institutions, factories, businesses and a huge number of base transceiver stations of a telecommunication networks to name a few, whose main sources of energy supply are fossil fuel-fired generators. However, these generators come in different capacities depending on the energy demand by the users. The study areas are the Main Campus of University of Jos situated on Bautchi Road, Permanent Site Campus of University of Jos situated opposite Angwa Rimi Quarters and the Bidabidi Quarters along Zaria Road which is a residential area (see Table 1). These were selected based on the availability of generator types commonly use, sites’ accessibility for monitoring and isolation from any known emission sources. Based on preliminary survey conducted...
before investigation, the following generator types were commonly use; 0.9 kVA gasoline-powered generators, 2.0 kVA gasoline-powered generators, 50 kVA Micano diesel-powered generators, 50 kVA CAT diesel-powered generators, 100 kVA Micano diesel-powered generators and 250 kVA diesel-powered generators.

The 0.9kVA gasoline-powered generator was used to generate electricity for a barbing saloon, 2.0 kVA gasoline-fired generator for residential electricity generation for lighting and powering of electronic devices, 50 kVA Micano diesel-fired generator for powering a worship centre, 50 kVA CAT diesel-fired generator for base transceiver station of a telecommunication network operator, 100 kVA diesel-fired generator for base transceiver station of a telecommunication network operator and 250 kVA diesel-fired generator for powering some University buildings and halls.

| Gen. Type          | Exhaust Heights (m) | LOCATION                                      | COORD                          | Elev. (m) | FUEL USED |
|--------------------|---------------------|-----------------------------------------------|--------------------------------|-----------|-----------|
| 0.9kVA             | 0.2                 | Bida-bidi, Behind PTS, Zaria Road Jos         | N09°58'49.6" E008°51'05.9"     | 1152      | Gasoline  |
| 2.0kVA             | 0.3                 | Bida-bidi, Behind PTS, Zaria Road Jos         | N09°58'49.6" E008°51'08.9"     | 1150      | Gasoline  |
| 100kVA (MICANO)    | 1.7                 | Main Campus of Unijos, Bauchi Road, Jos        | N09°56'54.0" E008°51'17.1"     | 1160      | Diesel    |
| 250kVA (MICANO)    | 4.0                 | Main Campus of Unijos, Bauchi Road, Jos        | N09°56'52.1" E008°53'27.8"     | 1162      | Diesel    |
| 50kVA (CAT Generator) | 2.2              | Permanent site of Unijos, Naraguta, Jos       | N09°58'04.9" E008°53'12.9"     | 1122      | Diesel    |
| 50kVA (MICANO Generator) | 1.5             | Permanent site of Unijos, Naraguta, Jos       | N09°58'13.4" E008°53'47.8"     | 1122      | Diesel    |
2.2. Monitoring Procedure

Six fossil fuel-fired generators ranging from 0.9 kVA to 250 kVA installed capacities and different brands were selected for this study and investigated for comparative assessment of their emissions' levels.

In this study, direct measurement was deployed in actively sampling the selected pollutants' levels released from the selected fossil fuel-fired generators weekly for a period of one year (November, 2015-October, 2016). The method used by [16] in experimentally measuring the concentrations of CO, CO$_2$ and PM$_{2.5}$ at 1.0 m from different capacity diesel-fired generators at various locations at Sango, Ado-Odo/Ota Local Government Area (LGA) of Ogun State, Nigeria was adopted for this study. In this work, active devices were placed at a height of about 1.2 meters above the ground level which is the average height of breathing zone of human being. Five different readings were taken at five to six receptor locations downwind the generators depending on the immediate presence of obstruction along the plume spread. This process was repeated for individual devices employed for the data sampling for the monitoring days to ascertain the concentration of each of the selected gaseous pollutants (CO, SO$_2$ and H$_2$S) and particulate matter (PM$_{2.5}$ and PM$_{10}$) released from the combustion of the fossil fuel from these generators. In the same vein, background pollutants' levels were sourced at the anti-plume direction. According to [8], most methods for regulated gas pollutants (e.g. CO, NO$_2$, ozone, and SO$_2$) use in-situ continuous monitors for hourly averaged concentrations.

The combustion generators were treated as point sources (considering each individual generator).

2.3. Estimation of the Emission Rate of Pollutants from the Selected Fossil Fuel-fired Generators

Estimation of the emission rates of these generators is a vital step in ascertaining their emission characteristics. The Emission rate of every fossil fuel-fired generator selected was obtained by averaging the values of the pollutants' concentration measured at 1.0 m from their exhaust pipes depending on the direction of these pipes. To determine this, in-situ measurements of the concentrations of CO, SO$_2$ and H$_2$S obtained at 1.0 m from the respective generators under investigation were used. Downwind distance of 1.0 m was chosen because emission rate, which is a function of source emission characteristics and geometry, dominates the dispersion rate at points very close to the emission source(s).

As a monitoring tool, modeling is generally an effective replacement for direct field measurement of ambient air quality. It is a proficient alternative to direct monitoring. Computer models are often used to simulate the levels of pollutants emitted from various types of sources, and their environmental impact over a specified period. In this work, Gaussian plume equation was adopted in determining the emission rate from the selected fossil fuel-fired generators. Gaussian plume model uses a realistic description of dispersion, where it represents an analytical solution to the
diffusion equation for idealized circumstances such as the emissions from fossil fuel-fired generators.

For a ground level source with no significant effective plume rise (i.e. $H=0$), Gaussian plume model formulated equation (1) in its modified form [17]:

$$C(x,0,0,0) = \frac{Q}{\pi u \sigma_y \sigma_z}$$  \hspace{1cm} (1)

where $C(x,0,0,0)$ is ground level concentration in the plume direction, $Q$ is the Emission rate or strength of source in mg/s, $\sigma_z$ is vertical dispersion coefficient in metre, $\sigma_y$ is the cross wind dispersion coefficient in metre, $u$ is the surface wind speed in m/s, $\pi$ = 3.142

Equation (1) was modified to equation (2) to determine the emission rates from these generators.

$$Q = \pi u \sigma_y \sigma_z$$  \hspace{1cm} (2)

The dispersion parameters, $\sigma_y$ and $\sigma_z$ were computed using the Briggs’ interpolation equations in equation (3) and (4) for neutral atmospheric stability conditions for urban areas which are dependent on downwind distances only [18].

$$\sigma_z = 0.14X (1 + 0.0003X)^{-1/2}$$  \hspace{1cm} (3)

$$\sigma_y = 0.16X (1 + 0.004X)^{-1/2}$$  \hspace{1cm} (4)

The mean surface wind speed for the period of sampling (November, 2015 to October, 2016) was obtained from Nigeria Meteorological Agency (NIMET) to be (6.9526 ±0.41605) m/s.

2.4. Statistical Analysis

The SPSS statistical software was used to obtain the descriptive analysis of the sampled ambient data from the selected generators. From these, the mean, standard error, standard deviation, minimum and maximum pollutants’ levels from different fossil fuel-fired generators at specified receptor locations were determined. Also bar charts were drawn using the micro soft excel graphing tools to depict the comparative magnitude of monitored pollutants from these generators at the specified receptor location downwind.

3. Results and Discussion

3.1. Mean Concentrations of Selected Pollutants at 1.0 m downwind the Fossil Fuel-fired Generators

The emission characteristics of the selected fossil-fueled generators investigated in this study in terms of the fuel type and exhaust orientation and height are herein reported. The mean concentration of pollutants (CO, SO$_2$, H$_2$S, PM$_{2.5}$ and PM$_{10}$) emitted from the selected fossil fuel-fired generators within their microenvironments (at 1.0 m) in the windward directions are presented in Table 2 for the monitored sites at Bidabidi, Permanent Site campus of University of Jos and Main campus of University of Jos, respectively.

It was observed that the mean concentration of carbon (II) oxide CO emission was significantly high at the receptor locations of 1.0 m downwind for the selected generators except that of CAT 50 kVA generator. This is a valid justification of the several observations presented in body of literatures that the dominant sources of outdoor concentrations of CO in urban areas are on-road transportation (gasoline- or diesel-powered engines) [19], off-road engines, and biomass burning activity. An insightful analysis of the observed Carbon (II) oxide levels shows that the two gasoline-fired generators have the highest CO emission levels (see Figure 2) despite their low capacities and power rating. Structurally, the selected gasoline-fired generators (see plate 1 and plate 3) were designed with limited chamber for air/fuel mixing which could inhibit complete combustion of fuel, hence, the elevated levels of CO emission. The formation of CO is largely due to poor mixing of combustion air and combustion fuel, resulting in incomplete combustion. Also, the percentage composition of approximate elemental structure of an average crude oil consists of 84% carbon, 14% hydrogen, 1-3% sulfur, and less than 1% nitrogen, oxygen atoms, metals, and salts [1]. This shows that with limited air/fuel mixing, CO will be a significant emission in any fossil fuel-fired generator since the relative abundance of the emission constituents depends on the fuel type and combustion conditions.

In the same vein, it was observed from the mean concentration of sulphur (IV) oxide and hydrogen sulphide that among the selected generators, Micano 50kVA and 100 kVA generators have the highest emission levels for SO$_2$ and H$_2$S (see Figure 3 and Figure 4) while CAT 50 kVA generator has the least emission levels for all the selected gaseous pollutants. This could be due to interplay of several factors, such as: the ages of the selected generators, the frequency of maintenance of these generators by the operators, the fuel types use and the frequency of usage, to mention but a few.

The observed mean concentrations of PM$_{2.5}$ and PM$_{10}$ are lower than the gaseous emissions.

This, according to [1], is because; gas and oil facilities burn the fuel with minimal on-site processing before combustion (see Figure 5 and Figure 6).

Generally, it was observed that pollutants concentrations at 1.0 m are vital in ascertaining the emission characteristics of the respective generators. The microenvironments around the fossil fuel-fired generators experience the forceful impact of the momentum and buoyant releases of pollutants before reasonable dispersion takes place. In this zone (<1.0 m from the source), emission rates are prevalent over dispersion. However, as the pollutants are being transported farther downwind, dispersion process increases along the plume spread within microenvironments (assuming the emission rate remains constant from the emission sources), the more the plume spread as a result of dispersion, the greater the volume of air available for dilution of pollutants.
**Table 2. Mean Concentration of Pollutants emitted from Diesel-fired Generator at Downwind Distance of 1.0 m**

| Pollutants  | Mean (mgm⁻³) | Pollutants  | Mean (mgm⁻³) | Pollutants  | Mean (mgm⁻³) |
|-------------|--------------|-------------|--------------|-------------|--------------|
|             | Statistic    | Std. Error  | Statistic    | Std. Error  | Statistic    | Std. Error  |
| 0.9kVA (CO) | 191.10       | 33.033      | CAT.50kVA (CO) | 2.280  | 0.000        | MICANO250kVA M/CAMP(CO) | 0.154  | 0.106 |
| 0.9kVA (SO₂) | 2.030        | 0.444       | CAT.50kVA (SO₂) | 0.150  | 0.094        | MICANO250kVA M/CAMP(SO₂) | 0.231  | 0.089 |
| 0.9kVA (H₂S) | 1.300        | 0.211       | CAT.50kVA (H₂S) | 0.354  | 0.090        | MICANO250kVA M/CAMP(H₂S) | 0.299  | 0.207 |
| 0.9kVA (PM₂.₅) | 0.031       | 0.000       | CAT.50kVA (PM₂.₅) | 0.002  | 0.000        | MICANO250kVA M/CAMP(PM₂.₅) | 0.005  | 0.001 |
| 0.9kVA (PM₁₀) | 0.060        | 0.010       | CAT.50kVA (PM₁₀) | 0.005  | 0.000        | MICANO250kVA M/CAMP(PM₁₀) | 0.016  | 0.007 |
| 2.0kVA (CO) | 220.120       | 75.048      | MICANO 50kVA (CO) | 25.489 | 3.537       | MICANO 100kVA M/CAMP (CO) | 19.810 | 5.169 |
| 2.0kVA (SO₂) | 2.208        | 0.350       | MICANO 50kVA (SO₂) | 4.648  | 0.561       | MICANO 100kVA M/CAMP (SO₂) | 1.894  | 0.409 |
| 2.0kVA (H₂S) | 1.034        | 0.233       | MICANO 50kVA (H₂S) | 3.661  | 0.729       | MICANO 100kVA M/CAMP (H₂S) | 1.878  | 0.304 |
| 2.0kVA (PM₂.₅) | 0.008        | 0.003       | MICANO 50kVA (PM₂.₅) | 0.079  | 0.010       | MICANO 100kVA M/CAMP (PM₂.₅) | 0.122  | 0.032 |
| 2.0kVA (PM₁₀) | 0.016        | 0.007       | MICANO 50kVA (PM₁₀) | 0.168  | 0.022       | MICANO 100kVA M/CAMP (PM₁₀) | 0.259  | 0.076 |

**Figure 2.** Mean CO emitted from the Selected Fossil fuel-fired Gen

**Figure 3.** Mean SO₂ emitted from the Selected Fossil fuel-fired Gen

**Figure 4.** Mean H₂S emitted from the Selected Fossil fuel-fired Gen
Figure 5. Mean PM$_{2.5}$ emitted from the Selected Fossil fuel-fired Gen

Figure 6. Mean PM$_{10}$ emitted from the Selected Fossil fuel-fired Gen

Table 3. Mean Concentration of Pollutants within the Microenvironments of Selected Fossil-fuel Powered Generators

| Pollutants   | Range (mg/m$^3$) | Minimum (mg/m$^3$) | Maximum (mg/m$^3$) | Mean (mg/m$^3$) | Std. Deviation |
|--------------|------------------|--------------------|--------------------|-----------------|----------------|
|              | Statistic        | Statistic          | Statistic          | Statistic       | Statistic      |
| 0.9kVA (CO)  | 100.400          | 0.000              | 100.400            | 55.778          | 4.115          | 22.537        |
| 0.9kVA (SO$_2$) | 2.100          | 0.000              | 2.100              | 0.974           | 0.100          | 0.550         |
| 0.9kVA (H$_2$S) | 1.390          | 0.000              | 1.390              | 0.355           | 0.110          | 0.605         |
| 0.9kVA (PM$_{2.5}$) | 0.210         | 0.000              | 0.220              | 0.050           | 0.009          | 0.051         |
| 0.9kVA (PM$_{10}$) | 0.410         | 0.010              | 0.410              | 0.101           | 0.018          | 0.099         |
| 2.0kVA (CO)   | 0.000            | 0.000              | 0.000              | 0.002           | 0.000          | 0.000         |
| 2.0kVA (SO$_2$) | 0.355            | 0.000              | 0.355              | 0.110           | 0.050          | 0.160         |
| 2.0kVA (H$_2$S) | 0.101            | 0.000              | 0.101              | 0.018           | 0.009          | 0.099         |
| 2.0kVA (PM$_{2.5}$) | 0.210         | 0.000              | 0.220              | 0.050           | 0.009          | 0.051         |
| 2.0kVA (PM$_{10}$) | 0.410         | 0.010              | 0.410              | 0.101           | 0.018          | 0.099         |
| CAT.50kVA (CO) | 0.000            | 0.000              | 0.000              | 0.002           | 0.000          | 0.000         |
| CAT.50kVA (SO$_2$) | 0.355            | 0.000              | 0.355              | 0.110           | 0.050          | 0.160         |
| CAT.50kVA (H$_2$S) | 0.101            | 0.000              | 0.101              | 0.018           | 0.009          | 0.099         |
| CAT.50kVA (PM$_{2.5}$) | 0.210         | 0.000              | 0.220              | 0.050           | 0.009          | 0.051         |
| CAT.50kVA (PM$_{10}$) | 0.410         | 0.010              | 0.410              | 0.101           | 0.018          | 0.099         |
| MICANO 50kVA (CO) | 0.000            | 0.000              | 0.000              | 0.002           | 0.000          | 0.000         |
| MICANO 50kVA (SO$_2$) | 0.355            | 0.000              | 0.355              | 0.110           | 0.050          | 0.160         |
| MICANO 50kVA (H$_2$S) | 0.101            | 0.000              | 0.101              | 0.018           | 0.009          | 0.099         |
| MICANO 50kVA (PM$_{2.5}$) | 0.210         | 0.000              | 0.220              | 0.050           | 0.009          | 0.051         |
| MICANO 50kVA (PM$_{10}$) | 0.410         | 0.010              | 0.410              | 0.101           | 0.018          | 0.099         |
| MICANO 250kVA M/CAMP (CO) | 1.150        | 0.000              | 1.150              | 0.216           | 0.059          | 0.382         |
| MICANO 250kVA M/CAMP (SO$_2$) | 1.960        | 0.000              | 1.960              | 0.491           | 0.072          | 0.464         |
| MICANO 250kVA M/CAMP (H$_2$S) | 1.740        | 0.000              | 1.740              | 0.529           | 0.093          | 0.600         |
| MICANO 100kVA M/CAMP (CO) | 37.380      | 0.000              | 37.380             | 8.438           | 1.865          | 9.324         |
| MICANO 100kVA M/CAMP (SO$_2$) | 3.140       | 0.260              | 3.400              | 1.215           | 0.132          | 0.659         |
| MICANO 100kVA M/CAMP (H$_2$S) | 2.780       | 0.000              | 2.780              | 1.084           | 0.159          | 0.795         |
| MICANO 100kVA M/CAMP (PM$_{2.5}$) | 0.220       | 0.010              | 0.230              | 0.068           | 0.011          | 0.055         |
| MICANO 100kVA M/CAMP (PM$_{10}$) | 0.500       | 0.020              | 0.520              | 0.145           | 0.024          | 0.121         |
3.2. Emission Rates of the Selected Fossil Fuel-fired Generators

The emission rate of a pollutant is the product of the measured pollutant concentration and the measured effluent flow rate. There were no instruments for determining the effluent flow rate, hence, the application of Gaussian plume model in equation 2 for predicting the emission rates of the selected fossil fuel-fired generators. The results obtained are presented in Table 3. From Table 3 and Figure 12, it is clearly depicted that 2.0 kVA and 0.9 kVA gasoline-fueled generators have the highest emission rates of 107.67 mg/s and 93.48 mg/s, respectively for CO while the Micano 50 kVA diesel-fired generator has the highest emission rates of 2.27 mg/s and 1.79 mg/s for SO₂ and H₂S, respectively. Comparatively observing Figure 12 & Figure 13 shows that the emission rates of these pollutants follow almost the same trend as the magnitude of the pollutant’s levels emitted within the microenvironments (downwind distances < 10.0 m). The little variation could be as a result of atmospheric turbulence within the domain on which these generators were located at the time of operation. Hence, in order to ascertain the emission characteristics which determine the magnitude of emissions from any generator, emission rate is vital since the variation in fuel composition, % sulphur content, ages of the generators and their maintenance culture are variables that cannot be readily determined. Also, the lack of equipment to carry out in-situ measurements of these emission characteristics such as volumetric flow rate, temperature of the flue gases, pressure of the flue gases, viscosity of the fuel and many more has made this approach of deploying the Gaussian plume equation in determining emission rate as an effective method. Besides, a number of the selected generator exhaust pipes as shown in Plates 1-6 have non-uniform cross-sectional areas which make the determination of their emission rates to be inaccurate. The application of Gaussian Plume Model in simulating emissions’ concentrations from point sources has been deployed by several researchers. According to a research by [16] conducted at Sango, Ado-Odo/Ota Local Government Area (LGA) of Ogun State, Nigeria on various diesel-fired generators used to powered base transceiver stations, the emitted mean CO level from some selected diesel generators was 44.68 ± 2.29 mg/m³ at 1.0 m downwind. In this work, the mean CO level emitted from similar generators were 25.49 ± 3.54 mg/m³ and 19.81 ± 5.17 mg/m³ from Micano 50 kVA and 100 kVA generator, respectively at 1.0 m downwind. These are clearly lower than that reported by [16] though less significantly. This shows that this model can be justifiably deployed in estimating emission rates of pollutants from point sources such as generators emissions.

3.3. Mean Pollutants’ Levels Released within the Microenvironments of the Selected Generators

A better perspective on the potential impacts of air pollutants emitted from the selected generators is gained by considering the mean levels of these pollutants released within their microenvironments (at downwind distances < 10.0 m); more detailed descriptions of concentrations of the selected fossil fuel generators are presented in Table 4 and corroborated by Figure 12. In addition, Table 4 and Figure 12 show that gasoline-fueled generators have more CO levels within their microenvironments than the diesel-fired generators. Furthermore, based on the National Ambient Air Quality Standards presented in Table 5, the microenvironments of these gasoline-fueled generators are hazardous and pose great threats to public health since their ambient levels exceed the air quality standards for both 8-hour and 1-hour averages. According to [20], these levels will readily interfere with oxygen uptake into the blood (chronic anoxia), heart and brain damage impaired perception, asphyxiation, weakness, headache and nausea of the people that are exposed consistently. However, other diesel fired generators are slightly below the air quality levels, though yet significant.

### Table 4. Emission Rates for selected Fossil fuel-fired Generators.

| S/NO | SOURCES | WIND SPEED AT POINT OF ADVECTION(m/s) | CO   | SO₂(mg/s) | H₂S |
|------|---------|--------------------------------------|------|-----------|-----|
| 1    | 0.9kVA Gen. | 6.95                                | 93.48| 0.99      | 0.64|
| 2    | 2.0 kVA Gen. | 6.95                                | 107.67| 1.08      | 0.51|
| 3    | CAT 50kVA Gen. | 6.95                                | 1.12 | 0.07      | 0.17|
| 4    | Micano 50 kVA Gen. | 6.95                                | 12.47| 2.27      | 1.79|
| 5    | Micano 250 kVA Gen. | 6.95                                | 0.08 | 0.11      | 0.15|
| 6    | Micano 100 kVA Gen. | 6.95                                | 9.69 | 0.93      | 0.92|

### Table 5. National Ambient Air Quality Standard

| S/N  | POLLUTANTS               | AVERAGING TIME | AMBIENT AIR QUALITY STANDARD | STANDARD TYPE |
|------|--------------------------|----------------|----------------------------|---------------|
| 1    | Carbon (II) oxide, CO    | 8Hrs           | 10.00mg/m³                  | Primary       |
|      |                          | 1Hr            | 40 mg/m³                    | Primary       |
|      |                          | 1Hr            | 0.196mg/m³                  | Primary       |
| 2    | Sulphur (IV) oxide, SO₂  | Annual arithmetic mean | 0.08mg/m³ | Primary     |
|      |                          | 24 hrs.        | 0.365mg/m³                  | Primary       |
|      |                          | 3 Hrs.         | 1.3 mg/m³                   | Secondary     |
| 3    | Hydrogen Sulfide         | 1 Hr.          | No National Standards but 0.042 mg/m³ for California Standard | Primary |
| 4    | Respirable Particulate Matter (PM₂.₅) | 1 year.       | 0.012mg/m³                  | Primary       |
|      |                          | Annual Arithmetic Mean |                       |               |
| 5    | Fine Particulate Matter (PM₁₀) | 24 Hrs.       | 0.035mg/m³                  | Primary       |
|      |                          | 24 Hrs.        | 0.15 mg/m³                  | Primary       |
Also, comparing the observed sulphur (IV) oxide levels with the NAAQS of 0.136 mg/m$^3$ for 1 hour average shows that the microenvironments of all the selected fossil fuel-fired generators have high levels of SO$_2$ except that of CAT 50kVA generators (see Figure 8). However, of these, Micano 50 kVA generator has the highest level of SO$_2$ within its microenvironment. In this case, the ages of the generators, the exhausts’ heights and orientations could be a great influence. The MICANO 50kVA diesel-fired generator’s exhaust is oriented to face downward (see plate 5). This exhaust’s orientation does not enhance dispersion of pollutants but constrain them to hover within the immediate environment before eventual dispersion, hence, contributing to high SO$_2$ levels within some few metres from the generator. Also, there is no much volume of air for dilution since they are closely oriented to the ground level with little elevation. However, only CAT 50kVA diesel generator has its exhaust’s orientation upward (see plate 4) while the other fossil fuel-fired generators have their exhausts or chimneys oriented horizontally (see Plates 1, 2, 3, 5 and 6). The upward exhaust orientations as in the case of 50kVA CAT generator (see plate 4) causes the ejected plume to be lofted higher vertically into the atmosphere before the processes of dispersion and dilution enhanced by the horizontal wind speed take effect and bent the plume downwind; this results in low pollutants’ levels. In the case of generators with horizontal exhaust orientation, the
plumes are ejected horizontally with no much vertical distance to travel before dispersion and dilution within their microenvironments. The plumes are advected horizontally in limited volume of air without much of enhanced vertical mixing of pollutants, thereby elevating their levels within their respective microenvironments.

Generally, according to [8], SO2 in urban and industrialized areas is largely from the combustion without emission controls of sulfur-containing fuels and from uncontrolled metal processing facilities that roast sulfide ores to make metal oxides. Emissions inventories can provide a good understanding of the sources of SO2, given the ability to accurately estimate sulfur contents of fuels [21,22,23]. However, in Nigeria, such emission inventories are not readily available since businesses often do not regularly report on what gases and other pollutants are being released into the environment. SO2 emissions from natural sources are usually much lower than anthropogenic emissions because according to [24], fuels offer a wide range of sulphur contents. Hence, fossil fuel-fired generators are huge contributors to SO2 levels in Nigeria. Oil and its by-products are composed of between 0.1% sulphur (paraffin) and 3% (heavy fuel oil) in the form of sulphides and thiols. Gasoline contains minimal level of sulphur in the context of overall mass emissions, although there can be an odor problem from conversion to hydrogen sulphide (H2S) on catalytic converters.

According to [20], these levels of SO2 emitted from the selected fossil fuel-fired generators (except CAT 50 kVA generator) can affect the respiratory system and the functions of the lungs, and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract.

Furthermore, from the spectrum of emitted pollutants sampled, it was observed that the height of the exhausts of the respective generators selected for this study contributes to the magnitude pollutants’ concentration from any fossil fuel-fired generators. The exhaust heights of 0.2 m, 0.3 m, 2.2 m, 1.5 m, 4.0 m and 1.7 m were measured (see Table 1) for 0.9 kVA generator, 2.0 kVA generator, 50 kVA CAT generator, 50 kVA Micano generator, 250 kVA generator and 100 kVA Micano generator, respectively from the ground level (see Plates 1-6). These could have contributed to low levels of pollutants emitted from 50 kVA CAT generator and 250 kVA generator being with higher exhaust heights while the ones with lower exhausts (i.e. closer to the ground) have higher emissions for the gaseous pollutants. High exhausts release pollutants into greater volume of air which enhances dilution, hence resulting in lower concentration.

In the same vein, hydrogen sulphide emissions from the selected fossil fuel-fired generators exceeded the recommended California Air Quality Standards of 0.042 mg/m3 for 1 hour time average as depicted by Figure 9. This implies that the microenvironments of these fossil fuel-fired generators have adverse impacts on human and environmental health. However, there is no National Ambient Air Quality Standard for H2S.

According to [25], exposure to high levels of H2S can cause muscle cramps, low blood pressure, slow respiration and loss of consciousness. Short-term exposure to moderate concentrations of hydrogen sulphide (between 1 to 10 ppmv) will cause eye, nose, and throat irritation, nausea, dizziness, breathing problems, headaches, loss of appetite, and problems sleeping while an extended exposure will irritate breathing passages and may lead to pulmonary edema (fluid buildup in the lungs).

The particulate matter levels within the microenvironments of these generators were lower than the NAAQ standards (see Figure 10 & Figure 11). Generally, these generators do not have control equipment to collect particulate matter, as emissions of particulate matter are low for gas and generally low for oil. PM10 levels were below the NAAQ standards for all the investigated generators while PM2.5 levels exceeded the National Ambient Air Quality Standards for 0.9 kVA generator and Micano 100 kVA generator. However, PM10 levels are higher than PM2.5 levels because that size range (PM10) includes the particles between 2.5 μm and 10 μm in diameter, in addition to particles with diameters smaller than 2.5 μm. Also, according to [26], PM2.5 includes nuclei mode particles and accumulation mode particles and PM10 includes nuclei mode particles, accumulation mode particles, and coarse particles. Of these, the most health-damaging particles are those with a diameter of 10 microns or less, (≤ PM10), which can penetrate and lodge deep inside the lungs. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer.

![Figure 10. Mean Concentration of PM2.5 of Selected and Gen. and NAAQS Level](Image)
Although emissions from individual small unit generators, are relatively small per unit, collectively their emissions can be of concern, particularly where large numbers of sources are located in heavily populated areas and in clusters.

According to the report by [16], the mean emission level of PM$_{2.5}$ released from diesel-fired generators is $0.374 \pm 0.007$ mg/m$^3$ while in this work; its mean levels are $0.08 \pm 0.01$ mg/m$^3$ and $0.122 \pm 0.03$ mg/m$^3$ from Micano 50 kVA and 100 kVA, respectively at 1.0 m downwind. Again, these are lower but of this same order of magnitude with that reported by [16].

### List of Abbreviations

| Abbreviation | Full meaning |
|--------------|--------------|
| CO           | Carbon (II) oxide |
| SO$_2$       | Sulphur (IV) oxide |
| H$_2$S       | Hydrogen Sulphide |
| PM           | Particulate Matter |
| kVA          | Kilovolt Ampere |
| CAT          | Caterpillar Inc |
| ppmv         | Part per million volume |
| M/Camp       | Main Campus |

Figure 11. Mean Concentration of PM$_{10}$ of Selected Gen and NAAQS Level

Figure 12. Emission Rates of Pollutants from Selected Generators

Figure 13. Mean Concentrations of Gaseous Pollutants within the Microenvironment
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