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A Framework for Monitoring Air Pollution Produced by Diesel-Powered Generators Installed for GSM Base Stations in Nigeria

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Abstract—***A framework for assessing the level of the air pollutants emitted by diesel-powered generators installed for the base stations deployed in Nigeria is proposed. The framework includes procedures for measuring the levels of pollutants emitted by the generators and for determining whether or not the emission exceeds the prescribed limits.***

Keywords—**Diesel power generators in Nigeria, GSM base station power, air pollutants, generator emissions in Nigeria, diesel generator pollution**.

I. INTRODUCTION

A characteristic of the Global System for Mobile Communications (GSM) equipment deployed in Nigeria is their excessive dependence on diesel-power generators for electricity. The generators are installed with GSM equipment because of unreliable power supply in the country (Nkeleme and Udoh, 2013).The major components of GSM equipment include the base transceiver station (BTS) or base station, base controller system (BSC), and the network subsystem (NSS). GSM specification requirement sallow a BSC-NSS pair to subtend or serve multiple base stations. Thus for each diesel generator installed for the BSC-NSS pair, there are tens of generators installed for the base stations. The deployment equates tens of thousands of diesel-powered generators installed for GSM systems across the country, all of which emit pollution agents such as carbon monoxide and oxides of nitrogen as well as particulate matter (PM). Left unchecked, pollution from diesel engines causes human health problems that can be fatal (EPA, 2005; WHO, 2004). In addition, diesel engine pollution impacts the environment with known economic consequences.

The National Environmental Standards and Regulations Enforcement Agency (NESREA) is Nigeria's environment regulator charged with "protecting the environment and human health, ensure safety and general welfare, eliminate or minimize public and private losses due to activities of the telecommunications and broadcast industry" (NESREA, 2013, p. 2). As of this publication, the level of attention the Nigerian regulator has accorded pollutions from gasoline and diesel-powered generators in Nigeria are unclear. A search of the regulator's website and the website of its parent ministry revealed no sign of air quality standard enforcement guidelines to prevent the pollution of ambient air as practiced in other parts of the world. This and the apparent level of smog emanating from the diesel generators in many Nigerian cities and towns suggest a need for a national guideline for enforcing the adopted air quality standards to protect Nigerians and the nation from the health and economic hazards of man-made air pollution.

II.BACKGROUND

Diesel-powered generators, the main source of electric power to GSM infrastructure in Nigeria (Anayochukwu and Nnene, 2013), are notorious for emitting pollutants from burning heterogeneous mixture of diesel fuel and air (Khair and Jaaskelainen, 2015). The pollutants, sometimes visible as smoke, smog, or soot include oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO), sulphur dioxide (SO_2), and particulate matter(EPA, 2006).Collectively and individually, exposure to the pollutants endangers human health and the environment. For instance, diesel particulate matter (PM)is carcinogenic and responsible for a number of health problems. According the WHO (2006) exposure to fine PM"pollution is associated with significant adverse health effects that include shortness of breath, bronchitis, asthma attacks, heart attacks, and premature death" (p. 2).The organization further notes that in 2012, 3.7 million people suffered premature deaths worldwide as a result of outdoor air pollution. According to WHO, the deaths are attributable to exposure to small particulate matter, which cause cancers, cardiovascular and respiratory diseases.

The United States Environmental Protection Agency (EPA) observes thatNO_x and SO_2 cause both temporary and long-term respiratory symptoms, increased susceptibility to respiratory infection, and the formation of acid rain (2006).Voice of America News (2013) reported a Massachusetts Institute of Technology (MIT) study that blames 200,000 annual premature deaths in the United States on air pollution.

Particulate Matter (PM): Particulate matter refers to liquid or solid particles, some of which are large and can be observed as soot. PM is the principal component in diesel exhaust smoke and consists of sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, and water (Omidvarborna et al, 2014). According to WHO (2005), PM affects more people than any of the pollutants in diesel engine smoke. PM particles are fine in size and measure less than 10 microns in diameter, thus making it easy to penetrate deep into human lungs.PM particles that are up to 10µm in diameter are categorized PM_{10}, while those that are less than 2.5µm in diameter are categorized$PM_{2.5}$. The PM standards are expressed as mass of particles per volume of

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air (micrograms per cubic meter or $\mu g/m^3$). Air pollution can also be expressed as its air concentration in parts per million (ppm) by volume. The concentration is expressed by the following equation.

$$ppm = \mu g/m^3 \left(\frac{(0.08205 * T)}{M}\right) \quad (1)$$

Where $\mu g/m^3$ = Micrograms of pollutant per cubic meter of air at sea level atmospheric pressure and ***T***;ppm = Pollutant concentration by volume; T = Ambient temperature in Kevin (K); 1 K = 273.15 + °C; 0.08205 = Constant; M = Molecular mass or weight of the pollutant

Carbon Monoxide Carbon monoxide (CO) is another dangerous pollutantin diesel engine smoke, and has over a 200-fold greater affinity for haemoglobin than has oxygen (EPA-1, 2012). Thus, carbon monoxide can make haemoglobin incapable of carrying oxygen to tissues. Carbon monoxide emissions is measured in part per million (ppm). The United States Occupational and Safety Health Administration (OSHA) uses the standard in Table 3 for regulating carbon monoxide emissions.

Hydrocarbons (HC) are toxic chemical compounds of hydrogen and carbon that form from partially burned diesel or gasoline fuel and are expelled into air through the engine exhaust as a pollutant. HC is a cancer-causing agent and also responsible for the formation of ozone when it reacts with oxides of nitrogen (DOE Maryland, n.d.). The diesel generator is an important source and contributor to HC pollution.

Nitrogen Oxidesof nitrogen or NO_x refer to a group of highly reactive gases containing nitrogen and oxygen in varying amounts (Mass.gov, 2015). These oxides are formed naturally or from burning diesel fuel at high temperatures.

A.WHO Guidelines for Air Quality

To reduce the danger posed by air pollution and deaths associated with it, the World Heath Organization has provided global guidelines for emission control. The guidelines recommend the reduction of $PM_{10}$to as low as 50$\mu g/m^3$per year (WHO, 2005). The EPA has adopted PM_{10}level of35$\mu g/m^3$ and $PM_{2.5}$level of 15$\mu g/m^3$over a 24-hour period as the United States standard for particulate matter (EPA, 2012). Other countries including the European Union have set air quality standards and pollution thresholds for their countries. Table 1 shows a summary of daily (24 hours) thresholds for PM pollutant in selected countries.

Table 1. PM Pollution Threshold for Selected Countries with 24-Hour Averaging Time

Pollutant/ Concentration	WHO	Australia	Canada	China	EU
PM_{10} (μg	50	50	None	150	50
$PM_{2.5}$ (μ	20	25	28	75	25

The European Union (2010) specifies the threshold shown in Table 2 for other air pollutants apart from PM.

Table 2. Thresholds for Other Pollutants in EU Countries

Pollutant	Concentration Level ($\mu g/m^3$)	Averaging Period
SO_2	350	1 Hour
	125	24 Hours
NO_2	200	1 Hour
	N	1 Hour
CO	10	Max daily 8 hour mean
Ozone	120	Max daily 8 hour mean

Source: European Environmental Commission

Table 3 shows the EPA thresholds for air pollutants in the United States.

Table 3. Air Pollutant Threshold in United States

Pollutant		Concentration Level	Averaging Timing
Carbon Monoxide		9 ppm	8-hour
		35 ppm	1-hour
Nitrogen Dioxide		100 ppb	1-hour
		53 ppb	Annual
Ozone		0.075 ppm	8-hour
Particle Pollution	$PM_{2.5}$	12$\mu g/m^3$	Annual
		15 $\mu g/m^3$	Annual
		35 $\mu g/m^3$	24-hour
	PM_{10}	150 $\mu g/m^3$	24-hour
Sulphur Dioxide		75 ppb$^{(4)}$	1-hour
		0.5 ppm	3-hour

Source: EPA

Table 4 shows certain air pollutants limits adopted by Nigeria.

Table 4. Nigeria Air Pollution Standard

Pollutants	Prescribed Limit	Averaging Time
Particulates	250 $\mu g/m^3$	24-hour
	*600 $\mu g/m^3$	1-hour
Sulphur dioxide	0.01 ppm (26 $\mu g/m^3$)	24-hour
	0.1 ppm (26 $\mu g/m^3$	1-hour
Carbon monoxide	10 ppm (11.4 $\mu g/m^3$)	Daily average of hourly value
	20 ppm (22.8 $\mu g/m^3$)	8-hourly average
Nitrogen oxides (Nitrogen dioxide)	0.04 ppm-0.06 ppm (75.0 $\mu g/m^3$-113 $\mu g/m^3$)	Daily average of hourlyvalues (range)
Non-methane Hydrocarbon	160 $\mu g/m^3$	Daily average of 3-hourly values

Source: FEMA

III. LITERATURE REVIEW

Seminal studies have examined various dimensions of diesel generator emission pollution. Anayochukwu and

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Nnene (2013) assessed the environmental impact of power generation at GSM base station sites in Nigeria and concluded that the power generators used with GSM equipment emit significant quantity of NO_x, SO_2CO, PM, and HC pollutants into the environment. The authors cautioned that continuous use of diesel-only generators by GSM networks in Nigeria could generate pollution to the level of causing health epidemic in the country.

In a letter to the American Journal of Respiratory and Critical Care Medicine, Awofeso (2011) reported that over 90% of businesses and 30% of homes in Nigeria use diesel-powered generators, which add up to about 15 million generators that are in use in Africa's most populous nation. Despite the widespread use of diesel generators in homes and businesses, the GSM operators remain the focus of this paper because of their prolong use of generators as opposed to other businesses and homes in which diesel generators are only used some of the time. Awofeso also reported increased prevalence of asthma in adults, jumping from approximately 6.3% in 2003 to 13.7% in 2006. The rise corresponds to the period that GSM systems were being introduced and excitedly deployed in Nigeria. However, the implied association between increased cases of asthma and increased use of diesel generators in Nigeria is yet to be confirmed by a scientific study.

Moss and Gleave (2014) note that Nigeria is Africa's largest importer of diesel generators and that generators in the country produce about 29 million metric tons of CO_2pollution annually. According to the authors, the pollution in Nigeria is largely overlooked and unprotested.In their study of the effects of diesel-powered generator fumes on ambient air quality in three areas in Lagos State, Nigeria, Nnaji and Chimelu (2014) found significantly high concentration of CO, PM, $NO_x$and SO_2pollutants at all the three locations studied. In addition, the authors observed that the levels of the pollutants were higher than the levels adopted by Nigeria.

Predicting the impact of emissions ofSO_2, NO_x, and particulates from the pipe manufacturing industry on air quality in India was the subject of investigation by Bhanarkar et al (2010). The authors estimated the pollution potential of several stationary power pollution emission sources that included blast furnace, captive power production, and ductile iron spun pipe facility. Their investigation showed that concentration of oxides of sulphur and nitrogen from diesel generator power surpassed the maximum safe limits prescribed by the government while the concentration of the same agents from similar power sources was within the prescribed limits.

Mar, Koenig, and Primomo (2010) evaluated the effect of particulate matter in air pollution that included emission from diesel generators on hospital emergency visits for asthma in Tacoma area of Washington State in the United States. The researchers found a correlation between emergency hospital visits for asthma and daily $PM_{2.5}$ level. Further, the researchers detected a "significant association between [emergency department] ED visits for asthma and increased use of diesel generators" (2010, p. 1).

The preceding reviews highlight the need for the environmental regulators in Nigeria to conduct periodic emission checks on diesel-powered generators to ensure they conform to the prescribed emission standards. The checks measure the concentration (in unit mass) of regulated pollutants that include CO, NOx, PM, HC, and SO_2.

IV. METHODOLOGY

This framework recommends measuring a minimum of 20 base stations (five BTSs for each GSM service provider)that have been selected at random using a direct measure approach. The direct approach method is accurate and uses empirical data, which are collected bydirectly measuring the concentration of air pollutants in the stack gas. In this approach snapshots of the emission are taken followed by actual collection of samples that are then analyzed onsite or in an offsite lab (MDEQ, 2004). Each sample includes measures of the concentration of specific pollutants in the stack gas and the gas flow rate.

A. Examples of Pollutants to Measure

- Carbon monoxide (CO)
- Nitrogen oxides (NOx) expressed as NO_2
- Particulate matter (PM)
- Particulate matter less than 10 microns (PM_{10})
- Particulate matter less than 2.5 microns ($PM_{2.5}$)
- Sulfur oxides (SO_x) expressed as SO_2

B. Requirement

- Established procedure
- Experience with stack testing
- Equipment – Probe
- Equipment – Smoke Tester, e.g., Wagner6500 or Testco350 analyzer
- Data collection sheet (for auto and manual data collection)as in Table 5
- Software – for analysis

C. Measurement Steps

The following steps provided by Michigan Department of Environmental Quality (2004) can be used to measure and calculate the annual pollution rates.

1) Set up the measuring equipment per instruction manual.
2) Connect or insert the probe into the engine exhaust per instruction manual.
3) Program the equipment to collect data by the volume of air being sampled.
4) Start the equipment collect air stack samples, which should include measurements for the concentration of

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5) air specific pollutant (ASP) and the stack gas flow rate (SGFR).
6) Use the measured values to calculate the hourly mass emission rate (HMER) using the formula: HMER = ASP x SGFR (mg/m^3)
7) Convert the mass emission rate to a source specific mission factor (SSEF) using the formula: SSEF = HMER/HA (where HA is hourly activity or hourly material throughput during the stack test).
8) Determine the annual emission rate of the each air pollutant (AERoP) using the formula: AERoP = SSEF x AA (where AA is hourly activity or annual material throughput during the year).
9) Generate measurement report.

Table 5. Sample Data Capture Sheet

Project Name:				Date:	
Organisation:				Contact:	
Address 1:				Tel.:	
Address 2:				Cell:	
Process Description:				Fax:	
Regulatory Requirement:				E-mail:	
Steam Injection?	□ Yes □ No	Cooling Water?	□ Yes □ No	Required Delivery:	

Stack Gas Sample Stream Composition						
Component	**Ranges Measured**	**Minimum Concentration**	**Maximum Concentration**	**Normal Concentration**	**Maximum Allowable**[1]	**Comment**
CO (ppm)					5,000	
NO (ppm)					5,000	
NO_2 (ppm)					100	
NO_x (ppm)					5,000	
SO_2 (ppm)					5,000	
SO_3 (ppm)					50	
HCl (ppm)					0	
PM (grains/ft^3)					0.04	

Installation Data			
Parameter	**At Sample Point**	**At Analyser Location**	**At DAHS Display**
Ambient Temp. Range:		°C	°C
Ambient Humidity Range:		%	%
FEMA Rating:	□ 4 □ 4X	□ 12 □ 4 □ 4X	□ 1 □ 12 □ 4 □ 4X
Sample Line Length:	***Note:*** Maximum recommended length is 130 m. for $^3/_8$" sample line.		
Stack/Duct Diameter:	m	Stack Velocity:	m/sec.
Stack Flow Rate:	cfh	Fuel Flow:	scfh
Communication Interface:	□ Analog/Digital signals □ RS-232C □ RS-422		
Other. (Specify conditions such as dust, vibration, etc.)			

Available Field Utilities				
Power:	VAC	Hz	Phase: □ Single □ 3-phase	
Plant Air:	psig	scfm	°F (dewpoint)	
Instrument Air quality: (-10°C dew point and oil free)			□	Shop quality: □

Source: Horiba Highmark Analytics

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V. MEASUREMENT REPORT

The sample report sheet in Table 6 can be included in the measurements report.

Table 6. Sample Report Sheet

Pollutants		Prescribed Limit	Averaging Timing	Actual Limit
PM	PM	N/A	24-hour	______ $\mu g/m^3$
		N/A	Annual	______ $\mu g/m^3$
	PM	N/A	24-hour	______ $\mu g/m^3$
SO_2		0.01 ppm (26$\mu g/m^3$)	24-hour	____(26 $\mu g/m^3$)
		0.1 ppm (26 $\mu g/m^3$	1-hour	______ ($\mu g/m^3$)
CO		10 ppm (11.4 $\mu g/m^3$)	Daily average of hourly value	______ ($\mu g/m^3$)
		20 ppm (22.8 $\mu g/m^3$)	8-hourly average	______ ($\mu g/m^3$)
NO_x		0.04 ppm-0.06 ppm (75.0 $\mu g/m^3$-113 $\mu g/m^3$)	Daily average of hourly values (range)	______ ($\mu g/m^3$ ______ $\mu g/m^3$)
HC		160 $\mu g/m^3$	Daily average of 3-hourly values	______ $\mu g/m^3$

VI. DISCUSSIONS AND CONCLUSION

Nigeria has been plagued by acute electricity power shortage for decades because of what some have termed gross inability of licensed operators to generate, transmit, and distribute electricity to meet demands. Several articles, papers, and news reports have been written about the poor state of electricity supply in Nigeria. Describing the electric power situation in Nigeria as a crisis, This day, an influential Nigerian newspaper wrote "despite the unprecedented level of investment in the power sector and increase in electricity tariffs, power supply situation in Nigeria is getting worse day by day, with the gap between demand and supply widening sharply in the urban areas" (2013, p. 1). Premium Times (2015) reported that the country's "Senate President, Mark, bemoans poor electricity supply in Nigeria" (p. 1). Another national newspaper, Punch, quoted the country's Minister of Power as saying, "Total grid generation as at 6am on Saturday is 2,628.6MW" (2013, ¶5). For a country of about 170 million people with numerous businesses, such a total daily power output, less than $1/14$ of what South Africa with a smaller population produces, is grossly inadequate.

These facts have led millions of individuals and businesses in Nigeria to source their electricity using diesel and gasoline power generators. As a consequence, millions of generators are in use daily, with those of GSM operators constantly in operation and making the air pollution worse. One way to reduce the pollution rate is to monitor the emission levels of the generators to enforce the national air quality standard. Another approach is to encourage the use of low-emissions fuels and renewable combustion-free power sources, co-generation of power (WHO, 2005).

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