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Exhaust Emission Assessment of Diesel-Powered Light-Vehicle Engines and Generator Sets

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Abstract

Emissions are among the key contributors to air pollution in our world today. This paper focuses on assessing the exhaust emission of diesel-powered light vehicle engines and generators in line with SG13, using Tarkwa a mining community in Ghana as the case study. Emissions such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), volatile organic compound (VOC), and hydrocarbon (HC) for 20 light vehicles and 20 generator sets that are powered by diesel fuel for mining operation were monitored using AutoPlus vehicle exhaust analyser and MiniRAE Lite system. The results obtained were analysed and compared with Environmental Protection Agency (EPA) and Optimal Performance Standards. The emission monitored for the light vehicles and generator sets passed all the EPA requirements except three generator sets which recorded higher values than the required 400ppm for NOx emission. None of the generator sets and light vehicles monitored met the air-to-fuel ratio value of 1, though they were close and in the range of 0.813 and 0.990, the CO_2 values recorded were below the ideal value of 15.5% for a perfectly working engine as specified by the Optimal Performance Standards. The exhaust emissions monitored conformed to the requirement set by the Environmental Protection Agency (EPA) of Ghana. This confirms the quality of diesel fuel used in Tarkwa, especially those supplied for mining operations.

Keywords: Emissions, Vehicle engines, Generator sets, Standards, Systems, Diesel Fuel, Optimal performance

Introduction

The majority of countries in the world are rapidly urbanising. Since the economic health of every nation depends on its citizens' freedom of movement and availability of electricity, transportation is seen as a major force behind rapid urban and economic development. Due to its versatility, road transportation stands out among the various modes of transportation as the most popular. Vehicles used in road transportation range in size from light-duty to heavy-duty and are typically propelled by internal combustion (IC) engines. Vehicle in use worldwide is estimated to be 1.3 billion.[1] Generator sets for electricity and internal combustion engines fuelled by fossil fuels emit harmful gaseous pollutants as well as particulate, which cause several environmental and health hazards and air pollution. At least 9 million people die from this every year, 85% of them in developing countries.[2-5] Approximately 600,000 deaths per year in Africa are attributed to air pollution.[6] According to International Energy Agency (2020),[7] transportation accounts for 24 percent of the world's direct carbon dioxide (CO_2) emissions from fuel combustion and is the source of carbon dioxide emissions from fossil fuels with the fastest rate of growth.[8,9] Other pollutants from vehicle emissions include particulate matter (PM), carbon monoxide (CO), ammonia compounds, sulphur oxides (SOx), nitrogen oxides (NOx), and non-methane volatile organic compounds (NMVOC).[10] Greenhouse Gases (GHGs) (CO_2, CH_4, N_2O, O_3, etc.) emissions from the worldwide transportation industry, which contribute to global warming and subsequent climate change, are the biggest environmental issue. Despite being the primary GHG, CO_2 has the lowest global warming potential (GWP), with methane (CH_4) and nitrous oxide (N_2O) having 28 and 265 times greater GWP, respectively, than CO_2 over a 100-year timeline,

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respectively.[11] Typically made up of solid carbonaceous particles and organic compounds, PM from vehicle exhaust can either deposit on the surface of the earth or remain suspended in the atmosphere. PM can be inhaled and is easily transported through the human respiratory system due to its tiny size (m-nm).

Because of the high health risks associated with vehicular emissions, most countries have imposed increasingly stringent emission legislations namely: Euro-VI in the European Union (EU); Tier-3 and California standards in the USA; China-6 in China; and BS-VI in India. The world-class standards are equivalent to Euro-VI for light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs). The Euro-VI standards will motivate researchers globally to explore and implement all possible modifications and improvements in the IC engines, their management, and after-treatment system design.[12] Several factors have an impact on vehicle emissions elements including vehicle characteristics (such as the vehicle's age, kind, emission controls, and operating circumstances), urban road type, and condition, frequency of vehicle maintenance, fuel type, and environmental factors (Temperature and Humidity), as well as the state of the traffic.[10,13] Over the years, original equipment manufacturers have relied on technology to lower car emissions. Some of the technologies that have been placed in automobiles to minimise NOx and CO_2 emissions include exhaust gas recirculation (EGR), three-way catalytic converters (TWC), lean NOx traps (LNT), and selective catalytic reduction (SCR).[9,14] Technologies like the variable geometry turbocharger (VGT), diesel particulate filters (DPF), and diesel oxidation catalysts (DOC) are now used in Euro 6 diesel engines to reduce PM emissions.[15] As with all machines, the efficiencies of these technologies reduce with age due to wear and tear. In order to improve our knowledge and pinpoint research gaps in this area, it is crucial to thoroughly analyse existing and emerging vehicle emissions monitoring systems.

The 2023 third-quarter petroleum downstream industry report indicates Ghana consumed a total of 1,129,338 mt of refined petroleum products, with the Western Region consuming about 17.4%. It is worth noting that majority of this fuel is supplied for mining operations in Tarkwa, a mining community with three major mining companies and its environs.[16-18] According to the Ghana's National Energy Transition Framework (2020 - 2070), the total national GHG emissions at the end of 2019 was 59.8MtCO_2e, with the energy sector accounting for approximately 46%. This paper monitored and assessed the exhaust emission from light vehicle engines and generator sets powered by diesel fuel using Tarkwa, a prominent mining community in Ghana as case study.

Methods Used

The AutoPlus Automotive exhaust analyser and MiniRAE Lite system were used to monitor the exhaust gases. The instrumentation and parameters are shown in Table 1.

Table 1: Instrumentation and Parameters

Instrument	Parameters	Monitoring Duration
AutoPlus Automotive	CO, HC, CO_2, O_2, NOx & Lambda(λ).	15 minutes
Exhaust Analyser		
MiniRAE Lite	Volatile Organic Compounds	15 minutes
	(VOC)	

Monitoring Procedure

CO, CO_2, HC, NOx, and Lambda (λ) were monitored using the AutoPlus vehicle exhaust analyser. The instrument was first turned on in a clean environment and autozero calibrated. After autozeroing, the instrument's probe was inserted into the exhaust tailpipe of the vehicles or generators and allowed time for the reading of parameters. VOC monitoring was conducted using the MiniRAE Lite system. First, the instrument was turned on and self-testing was allowed to complete. Then, the probe was inserted into the sampling port for 15 minutes, and the peak VOC value was recorded.

Results and Discussion

Data analysis

The data analysis conducted for the emission monitoring of the light vehicle engines and generator sets is shown in Table 2 and 3 respectively.

Emissions from vehicles' tailpipes and generator sets often contain pollutants that can be detrimental to human health.[3-5,12,19] Parameters that are usually monitored include Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxygen (O_2), Hydrocarbon (HC), and Lambda (λ). However, the emission status of a vehicle or generator is made by comparing only the CO and HC readings with the recommended standards. For a vehicle to pass the emission test, both the CO and HC readings must be below or equal to the recommended standards. If both the CO and HC or either CO or HC is above the standard, the vehicle has failed the emission test. Emission analysis interpretation involves the use of emission test results to determine emission status and provide advisory information to vehicle owners about the performance of their vehicle's engine. It involves comparing values of the test parameters against specific set standards. The analysis of the emission results of the various test parameters, their ideal values and/or standards, and comparison are provided as follows:

EPA standards put an upper limit for generator sets exhaust emission for CO, HC, and NOx as 3.5%, 1200 ppm, and 400 ppm respectively. All the 20 generator sets monitored met the EPA requirements for CO and HC. However, 3 generator sets, that is numbers 7, 10, 20 recorded NOx values of 611 ppm, 512 ppm, and 480 ppm respectively which are higher than the maximum limit of 400 ppm. Optimal performance standards for generator sets have maximum limits of 2% for CO, 120 ppm for HC, 15.5% for CO_2, and 1 for air-to-fuel ratio (λ). All the generator sets met the CO maximum limit of 2%, however CO_2 values recorded failed to meet the ideal limit of 15.5%. However, only three generator sets, that is numbers 11, 15, and 19 met the HC maximum emission limit of 120 ppm. None of the generator sets met the air-to-fuel ratio value of 1, though they were all close. The lowest value was 0.813 for generator number 5 and the highest recorded value was 0.990 for generator number 19.

EPA standards have an upper limit for light vehicle exhaust emission for CO as 3.5% and for HC as 1200 ppm. All the 20 light vehicles monitored met these maximum limits set by the EPA. The optimal performance standards for light vehicles have maximum limits of 2%, 120 ppm, 15.5%, and 1 for CO, HC, CO_2, and air-to-fuel ratio (λ) respectively. The results obtained indicate that all the light vehicles met the exhaust emission requirements for CO and CO_2 but none met the HC and air-to-fuel ratio requirements for optimal performance. However, the air-to-fuel ratio values were close to 1 and in the range of 0.820 and 0.980. To minimise emissions from vehicles and generator set it is required to adopt emissions control and monitoring strategies and posttreatment technologies such as improved vehicle design, new energy technologies, enhanced fuel quality, selective catalytic reduction (SCR) and selective noncatalytic reduction among other (SNCR).[9,14]

Table 2: Data Analysis for Light Vehicle ((LV) Engines Emission

Parameter	CO (%)	HC (ppm)	CO_2 (%)	NOx (ppm)	λ	VOC (ppm)
Range	0.03	899	3.1	504	0.16	71.1
Minimum	0	121	1.5	42	0.82	0
Maximum	0.03	1020	4.6	546	0.98	71.1
Mean	0.013	294.2	2.55	145.9	0.93	33.39
Standard Error	0.002	48.308	0.165	24.954	0.009	5.068
Standard Deviation	0.009	216.039	0.737	111.6	0.04	22.663
Variance	0	46672.8	0.544	12454	0.002	513.59
EPA Standard	3.5	1,200		400		
Optimal Performance Standard	2	0-120	15.5		1	

Table 3: Data Analysis for Generator Sets (GEN) Engines Emission

Parameter	CO (%)	HC (ppm)	CO_2 (%)	NOx (ppm)	λ	VOC (ppm)
Range	0.05	1016	3.6	551	0.177	379.5
Minimum	0	1	1	60	0.813	20.2
Maximum	0.05	1017	4.6	611	0.99	399.7
Mean	0.027	376.2	2.47	225.25	0.915	139.28
Std. Error	0.003	62.485	0.204	34.494	0.012	29.317
Std. Deviation	0.013	279.44	0.913	154.26	0.055	131.11
Variance	0	78086.7	0.833	23797	0.003	17189
EPA Standard	3.5	1,200		400		
Optimal Performance Standard	2	0-120	15.5		1	

Carbon monoxide (CO)

During an idle test, the normal CO reading for the combustion process succeeding at or near the stoichiometric point (Lambda of approximately 1) will typically measure less than 2%. However, the Ghana EPA has set an emission standard of 3.5% for vehicle emissions; hence all LVs and generators passed the CO test. Given the λ values recorded (all close to 1), it is thus in order that the recorded CO values for all LVs and generators were below 2% Figures 1f and 2f. High CO readings typically indicate that the engine is getting too much fuel and/or insufficient air (rich air/fuel mixture).[20] Circumstances that could lead to high CO emissions are low idle speed, improper float settings in carburetted vehicles, blocked air filters, excessively dirty or contaminated oil-saturated charcoal canister, non-functioning PCV valve system, and improper operation of the fuel delivery system.[9,10,21]

Carbon dioxide (CO_2)

It represents the "desirable" end-product produced when fuel is burned in the presence of oxygen to produce energy (combustion). Therefore, high CO_2 reading shows that the engine operates well without wasting fuel. This is termed as working efficiently. Generally speaking, the higher the CO_2, the more efficient an engine is. The ideal value of CO_2 for a perfectly working engine is about 15.5%. All the LVs and Generators recorded CO_2 values far below the 15.5% meaning the engines were performing below efficiency, as shown in Figures 1d and 2d respectively. Issues that can cause high CO_2 readings include problems in the engine such as air/fuel imbalances, misfires, engine mechanical problems, or sample dilution.[9,20,21]

Hydrocarbon (HC)

HC readings represent the amount of unburned fuel emitted from an engine's exhaust pipe. It is measured in 'ppm' (parts per million). The HC reading of a perfectly working engine should be about 00 – 120 ppm. However, the Ghana EPA recommends a 1200 ppm standard for vehicles. All the monitored engines passed the emission status test by EPA but recorded HC concentrations above the optimal range Figures 1e and 2e. Circumstances that could lead to high HC emissions, may include, a misfire from the secondary systems like fouled spark plugs and wires, rotor, ignition coil, or distribution cap, improper ignition timing, vacuum leak, or malfunctioning vacuum device, malfunctioning exhaust gas recirculation system faulty air pump, worn valves, seals, guides or piston rings, malfunctioning carburettor or fuel injection system non-functional catalytic converter among others.[9,10,21]

Lambda (λ)

The value of lambda shows the burning efficiency of an engine. In other words, it shows how well the engine combines air and fuel in the right proportions for combustion. In the ideal state, the lambda value is one (1). Lambda can be interchanged with AFR. A lambda value that is less than one indicates a condition of too much fuel than air (rich A/F mixture). However, a lambda value that is more than 1 indicates a condition of too much air than fuel (lean A/F mixture). A lambda value helps to validate the indication of the other parameters.[9] All the engines monitored recorded λ values below one (1) as shown in Figures 1b and 2b.

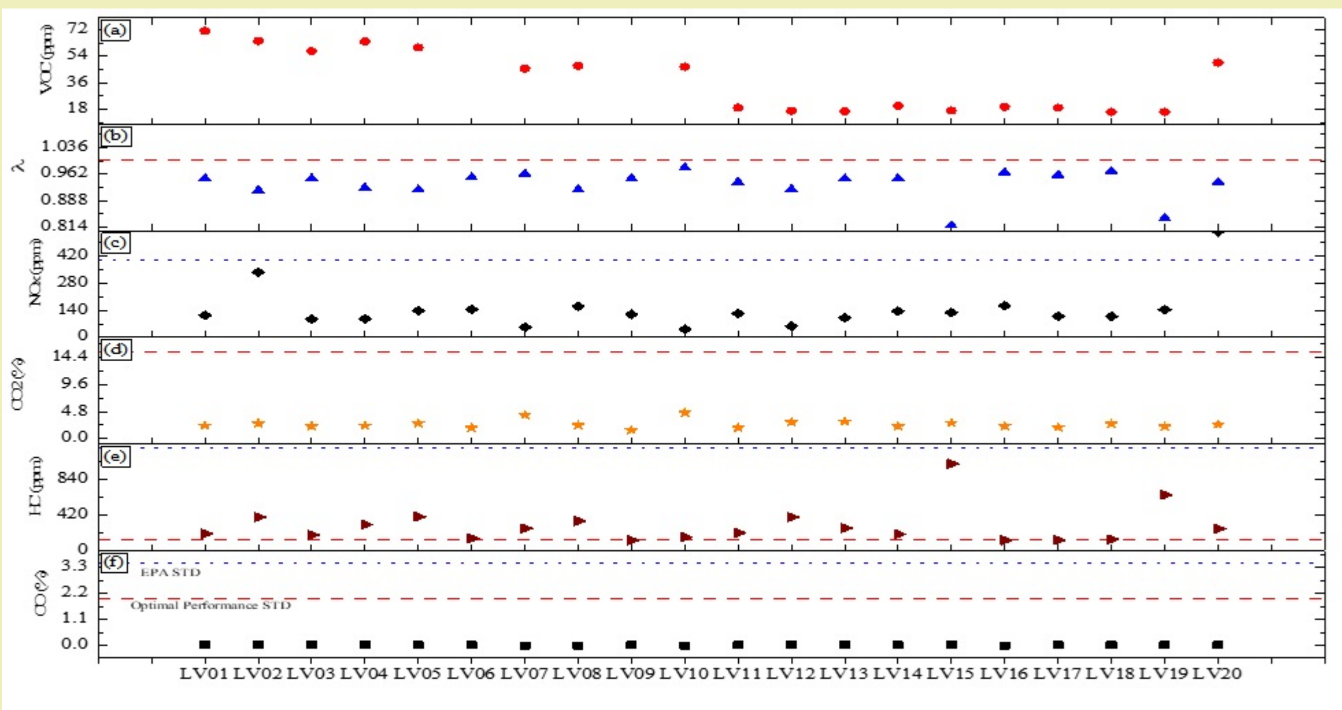

Figure 1: Boxplot for light vehicle engines exhaust emissions analysis

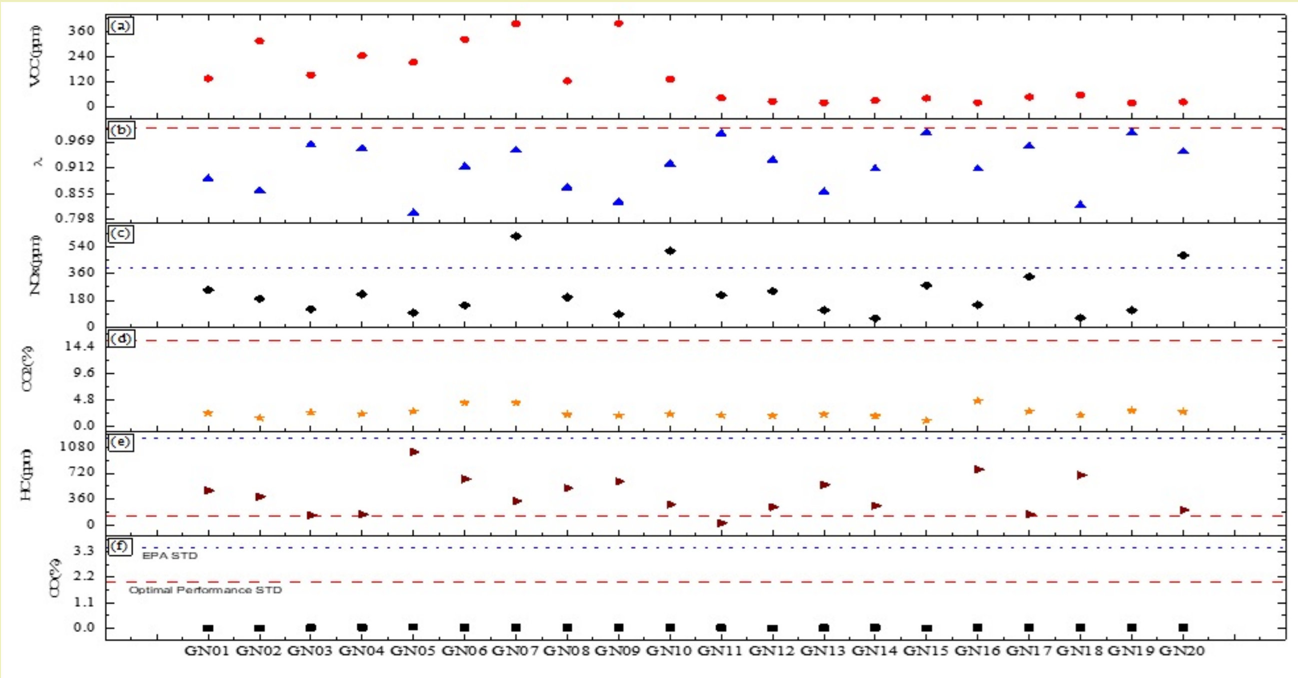

Figure 2: Boxplot for generator sets exhaust emissions analysis

Nitrogen oxides (NOx)

High levels of nitrogen oxide (NOx) can have a negative effect on vegetation, including leaf damage and reduced growth. In addition, NOx can fade and discolour furnishings and fabrics, reduce visibility, and react with surfaces. Elevated levels of NOx can cause damage to the human respiratory tract and increase a person's vulnerability to the severity of respiratory infections and asthma.[9,10,19,21] EPA has no vehicular emission limit for NOx but has set 400mg/Nm^3 standard for point source emission. All generator set emissions can be considered point source emissions hence the comparative analysis. The results shown in Figure 1c and Figure 2c confirm the NOx concentrations recorded were below the point source emission standard by EPA.

Volatile organic compounds (VOCs)

VOCs emissions from the combustion of diesel fuels are not regulated by the EPA and Optimal Performance Standards. However, when produced in high quantities can have detrimental effect because they have compounds that can form photochemical smog. VOCs emitted by engines are as a result of unburnt or incomplete combustion of fuels.[22,23] In general, the generator sets emitted higher VOCs values compared to the light vehicle engines. The highest VOCs values for light vehicle engines and generator sets are respectively 71.1 ppm and 399.7 ppm respectively Figures 1a and 2a.

Conclusion

This paper assessed the emissions from light vehicle engines and generator sets that are powered by diesel fuel for mining operation. The measured gases were compared with the EPA and Optimal Performance Standards. All twenty (20) Light Vehicle (LV) engines and twenty (20) Generator sets passed the Emission Status Test (EST) as stipulated in the EPA Standards. The engines of all LVs and Generator sets operated a little below optimal condition. All the exhaust emission tests (CO, CO_2, HC, VOC, NOx) for the 20 light vehicles and 20 generator sets conformed to the EPA standards, except three generator sets that recorded values higher than the NOx emission requirement of 400 ppm. This confirms that the quality of the diesel fuel used for powering engines for mining operation in the Tarkwa community is good. However, none of the generator sets and light vehicles engines met the air-to-fuel ratio value of 1 and the 15.5% ideal value of CO_2 for a perfectly working engine requirement by the Optimal Performance Standards.

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Conflicts of Interest

Regarding the publication of this article, the authors declare that they have no conflict of interest.

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