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Performance Evaluation of a Stationary Diesel Engine Emission Converter

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ABSTRACT

The poor power supply in Nigeria has necessitated every home, school, factories and multinationals to source for alternative power supply. For most homes, schools, factories and so on, the use of generating set is the only alternative option available. This has greatly increased noise and air pollution. The air pollution produced alongside with vehicle emission negatively impacts the quality of air in the surrounding environment. It is the goal of this study to develop a diesel engine emission converter (DEEconverter) that will be capable of purifying the exhaust of generating set before releasing it to the atmosphere. A mechanical device that performs similar operation as a catalytic converter was designed with two major assemblies namely filtration chamber assembly and absorption chamber assembly. The DEEconverter was analysed using AZ0004 CO_2 meter. The meter measures amount of CO_2 emission, temperature and humidity respectively. The components are linked so that there is no risk of pressure failure before the purified exhaust is released to the atmosphere. The DEEconverter was installed on a Yoshita 4950D series generator and it was run for a period of one hour. 2477 ppm of CO_2 was released to the atmosphere without the DEEconverter installed. The temperature and humidity were 34.8 ^oC and 51.4% respectively. With the DEEconverter installed, CO_2 released was 336 ppm, and the average temperature and humidity were 36.8 ^oC and 50.3% respectively. The emergence of DEEconverter is significant to a healthy environment and with the support of environmental agency; its mass production will provide job opportunities.

1. INTRODUCTION

Emissions from internal combustion engines (ICE) are of major concern because of the negative impact on air quality, human health, and global warming (Al-Baghdadi *et al.,* 2000; EPA, 2011). Therefore, there is a concerted effort by most governments to handle it by setting control measures. These undesirable emissions include black carbon (BC), unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), oxides (O_3), sulphuric oxides (SO_x) and particulate matter (PM) (Giwa *et al.*, 2014; Giwa *et al.*, 2017a). The increase in the amount of these undesirable emissions in the atmosphere would be significant enough to alter global climates and thereby leading to climate change which primarily affects human welfare. These emissions have environmental impacts that are both locally and globally oriented. Moreover, in recent years, air quality assessment has become a severe problem in many countries, and the interest to replace fossil fuels with renewable and sustainable energy sources has increased (Giwa *et al.*, 2014; Nwaokocha *et al.*, 2016, 2018).

The most common modern fuels are made up of hydrocarbons and are derived mostly from fossil fuels (petroleum). Fossil fuels include diesel fuel, gasoline and petroleum gas, and the rarer use of propane. Except for the fuel delivery components, most internal combustion engines that are designed for gasoline use can run on natural gas or liquefied petroleum gases with or without major modifications (Nwaokocha *et al.*, 2016). Large diesels can run with air mixed with gases and a pilot diesel fuel ignition injection. Liquid and gaseous biofuels, such as ethanol and biodiesel (a form of diesel fuel that is produced from crops that yield triglycerides such as soybean oil), can also be used. Engines with appropriate modifications can also run on hydrogen gas, wood gas, or charcoal gas, as well as from so-called producer gas made from other convenient biomass (Nwaokocha *et al.*, 2016).

Increased global warming resulting from the emission of greenhouse gases has received widespread attention. Among the greenhouse gases, carbon dioxide (CO_2) contributes more than 60% to global warming because of its huge emission amount (Albo *et al.*, 2010). The CO_2 concentration in atmosphere now is close to 400 ppm which is significantly higher than the pre-industrial level of about 300 ppm (Oh, 2010).

Environmental issues emanating as a result of emissions of pollutants from combustion of fossil fuels have become global problems, including air toxics, greenhouse gases (GHGs), particulate matter (Albo, 2010; Giwa *et al.*, 2017b). In Nigeria, current energy related activities (power and fuel consumption in transport sector) account for more than half (about 55%) of total national emissions (Giwa *et al.*, 2017a). Anomohanran, (2009) determined the GHG emission resulting from gas flaring activities in Nigerian. The study shows that the quantity of gas flared in Nigerian declined at a yearly rate of 10.5%. It also showed that the quantity of GHG emission resulting from gas flaring far exceed the emission from the consumption of petroleum product in Nigeria with an estimated revenue loss of 17 billion dollar. But recent work Giwa *et al.* (2014) studied the black carbon component in gas flaring activities in Nigeria. Their work revealed an estimated amount of 4.56×10^5 tons of black carbon released via gas flaring of 895.01 b cubic cm of gas that could have given of revenue of 94.84 billion dollars. GHG emission has greatly impacted on climate change. Although no region of the world will be entirely spared, the negative impacts are likely to fall most heavily on developing nations in the tropical region.

The role of engine design and emission control devices in minimizing the pollutants level of release (CO, NO_X unburned hydro-carbons (HC) and other particulate emissions) contributed by internal combustion engines is unequivocally important. The amount and the types of emissions change with a change in the industrial activities, technology, and a number of other factors, such as air pollution regulations and emissions controls. Methods or devices like electrostatic precipitators (wet and dry types), wet scrubbers, and cyclones (or multi cyclones) have been efficient in reducing the air pollution. The reduction of CO_2 via these mediums has been discovered to be 60% efficient, couple with the fact that they really don't last long.

It should be noted that the epileptic power supply in Nigerian has greatly increased the usage of generating sets particularly the diesel engine generating set which is known to have high amount of emission released into the atmosphere (Nwaokocha and Okezie, 2016; Nwaokocha *et al.*, 2018). Mitigation efforts to curb this emission released by this equipment are limited or practically nil (Nwaokocha and Okezie, 2016; Nwaokocha *et al.*, 2018). Roden *et al.* (2009) carried out a laboratory and field investigation of particulate matter and carbon monoxide emissions from household cooking equipment (cookstoves). It was reported from the study that a well designed equipment, capable of causing emission, can significantly reduce particulate matters and carbon monoxide emissions. It is the main goal of this study to design and improved emission control device for emission reduction of diesel engine generators.

2. MATERIALS AND METHODS

2.1. Pollutant Absorbing Substances

The following pollutant absorbing substances were identified as having emission absorbing capability:

1. Kankara Kaolin: The material was sourced locally in Ilaro, Ogun State, Southwest Nigeria.

2. Sodium Hydroxide (NaOH): Sourced locally from chemical stores in Lagos State Southwest Nigeria.

These two substances (Kankara kaolin and NaOH) were mixed at different proportion to form the Kankara-sodium hydroxide gel substrate. The Kankara was first soaked in deionized water for five days and after it was dried. In preparing the gel substrate, the proportion of NaOH in the gel substrate was varied from 5% to 50%.

2.2. Components of the Emission Control Device

The device has two parts namely, the filtration cylinder and the absorbing chamber as shown in Figure 1.

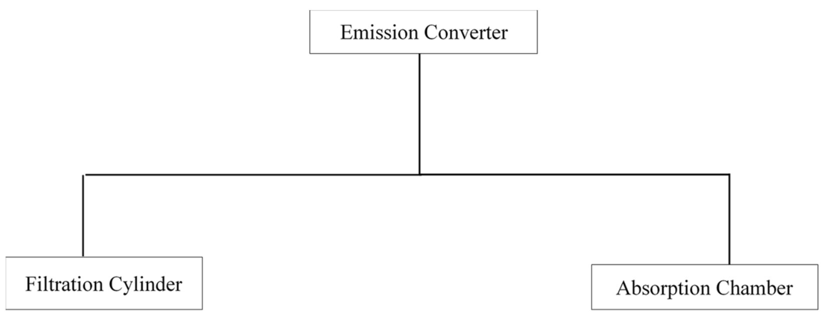

Figure 1: A flowchart of the emission converter

2.2.1. Filtration cylinder

This is the cylindrically shaped jar, where the smoke is first received for removal of small/tiny carbon particles. The filtration was achieved with the aid of a galvanized filtration stainless steel sheet. In the filtration cylinder are the followings components (see Figure 2):

- Galvanized filtration stainless steel sheet [ultra]: This is a filter steel that can collect very small particles and it's mostly used for collecting dirt in water filtration process. In this fabrication, it was used to collect carbon particles from the smoke coming from the generator exhaust.

- Cylinder [1 mm thick]: This is a cylindrically shaped metal jar in which the galvanized filtration stainless sheet was fixed, to collect tiny particles of carbon in the exhaust smoke as shown in Figure 3.

- 1 inch (1”) iron pipe: This pipe is meant to channel the smoke from the generator exhaust outlet to the filtration cylinder and channel the filtered smoke from the outlet of the filtration cylinder to the absorption chamber.

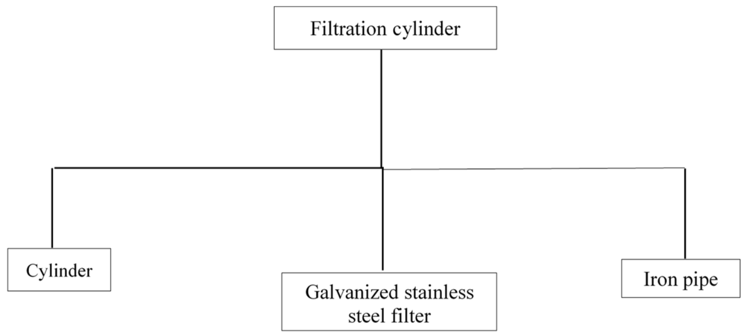

Figure 2: A flowchart of the filtration cylinder

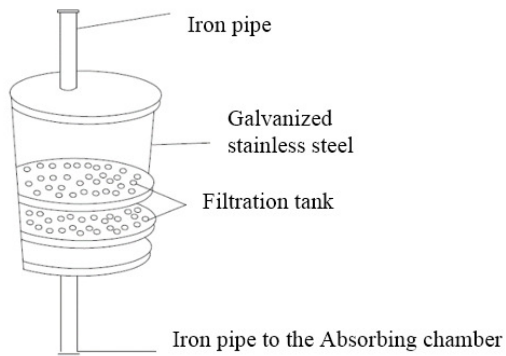

Figure 3: A schematic representation of the filtration cylinder

2.2.2. Absorption chamber

The absorption chamber is the final segment that contains the pollutants absorbing substance which has been prepared to absorb the pollutants. Considering a long working duration of the generator and the amount of smoke that would be released over that time, it was ensured that after the absorbing of the pollutant, there is an outlet for the purified smoke to avert pressure build up in the chamber. The absorption chamber has the following components as shown in Figure 4:

- Aluminum sheet metal: The sheet metal was used to make the chamber.

- Angle iron [1 mm thickness]: These are iron types usually in an angular form of 90 degrees. It was majorly used as stands in fabrication.

- Perforated metal plate [1 mm thickness]: The perforated metal sheet was used to design a tray. This tray was to carry the pollutant absorbing substance and also allow the continuity in flow/movement of the smoke.

The trays are made in two layers with each layer carrying the pollutant absorbing substance. The layer was doubled to ensure that there is an appropriate proportion of the chemical for the absorption of the carbon from the carbon monoxide.

- Flange one inch (1”): This is a ring to form a rim at the end of the pipe creating a flange joint connecting the pipe to the absorption chamber.

- Pollutant absorbing substance: This substance was beneficiated in order to increase its purity, by soaking in water for some specific days, and decanting on daily basis so as to achieve a desired result.

The modified DEEconverter is shown in Figure 5.

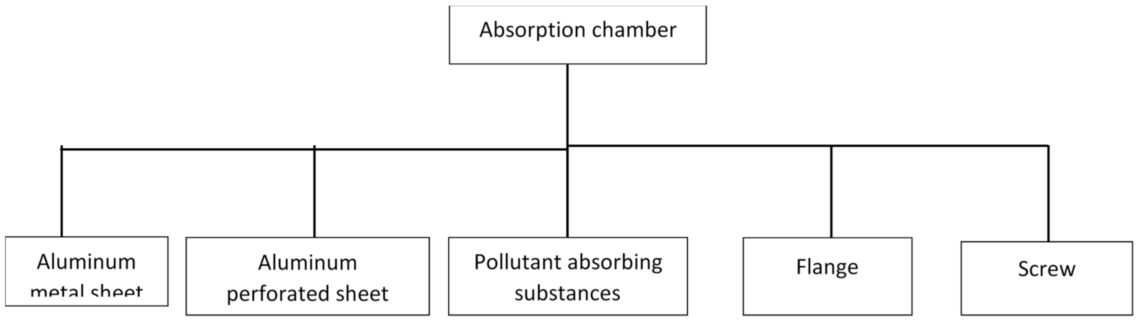

Figure 4: A flowchart of the absorption chamber

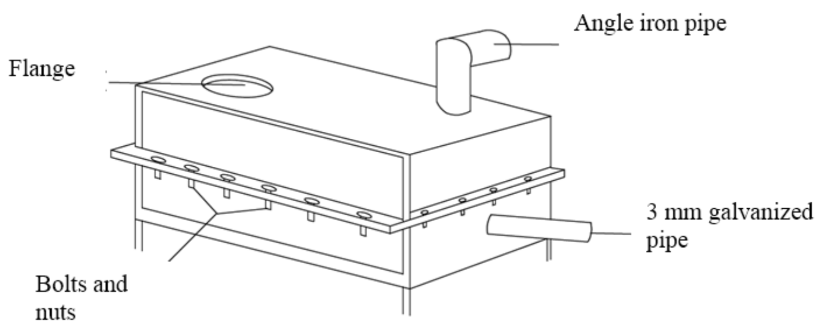

Figure 5: A diagram showing the emission device after modification

2.3. Performance Evaluation

The comparison of the before and after analysis of the generator emission formed the required evaluation. An emission/gas analyzer (AZ-0004 CO_2 Meter) was used to achieve this evaluation process. The experimental investigation was carried out with a thermometer with a range of 0 °C to 360 °C to take accurate readings of the exhaust temperature from the diesel engine. The Kaolin was beneficiated before preparing the gel substrate. Beneficiation process involves washing, removal of impurities, concentrating, sizing of particulates and aging. The beneficiated sample was washed thoroughly with deionized water until neutrality and mixed with calculated amount of Sodium Hydroxide (NaOH) with accurate mixing formation proportion needed for gel substrate. The product was mixed to obtain a proportion that resulted in increased toughness. This was allowed to age for 9 days in a quiescent condition. This gel formation was kept at the base of the chamber for final absorption and purification. The reactor consisted of inner and outer ceramic casing, heating coil attached to calibrate volt regulator and source of power supply. Iron pipe with openings at a point for final discharge of emissions and a point connected to the source of pollutant i.e. generator.

Wire mesh shaped into cylindrical structure containing the pollutant absorbing substance was fitly placed in the absorption chamber. The gas was trapped into the absorption chamber through the cylinder from the exhaust of the diesel generator for the reaction of pollutant absorbing substance and exhaust emissions to occur where the absorbing substance is placed on each layer in the absorption chamber. The treated emission leaves via the base of the chamber with the aid of the galvanized pipe. A measuring device (an analyzer) was placed at this point (galvanized pipe) where the final purification was measured in part per million (ppm), humidity and atmospheric air temperature.

The generator was operated for 10 minutes without attachment of the DEEconverter and emission data was collected at interval of 5 minutes for this time duration. Later the emission converter was attached to the diesel generator and operated for 60 minutes with emission data collected at interval of 5 minutes. The generator was switched off after the completion of experiment.

The rating of the diesel generator used for this evaluation task are as follows:

Engine Model: Yoshita 4950D series
No of Cylinders: 4
Cycle: 4 Strokes
Phase: 3
Generator Rating: 33 KVA
Maximum Power: 26 KW
Voltage: 415 V

3. RESULTS AND DISCUSSION

The generator was allowed to run for about 10 minutes with an exhaust temperature of about 53 ^oC and the emission data obtain is presented in Table 1.

Table 1: Emission data of experimental diesel engine without emission converter installed

Duration of running (Minutes)	Parts per million (ppm) of CO_2	Atmospheric temperature (°C)	Relative humidity (%)
0 – 5	1280	32.3	54.7
5 – 10	2477	34.8	51.4

Table 1 show the rate at which the emission increased. Within 10 minutes of operation, the emission increased from 1280 ppm to 2477 ppm of CO_2. Afterwards, the DEEconverter was installed on the generator for its evaluation. The generator was allowed to run for 60 minutes so as to give a clear evaluation of the DEEconverter. Table 2 shows the diesel engine exhaust emission data with DEEconverter installed on it. It should be noted that the exit of the DEEconverter was blocked for 10 minutes to allow reaction between the pollutant absorbing substance and generator exhaust. Afterwards the outlet was opened. The table shows a decrease in the amount of emission of the diesel generator when installed with the DEEconverter after an operating time of 60 minutes with an increase in air temperature and the generator maintaining a moderate relative humidity.

The result derived from Table 2 when the DEEconverter was installed on the diesel generator gives emission data to the generator namely parts per million of CO_2, average air temperature (^oC) and average relative humidity (%) measured at interval of 5 minutes. The average parts per million (ppm) of CO_2, average air temperature (^oC) and average relative humidity (%) of CO_2 was calculated to determine the performance of the DEEconverter when installed to the diesel generator.

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Table 2: Emission data of experimental diesel engine with emission converter installed

Duration of running (Minutes)	Parts per million (PPM) of CO_2	Atmospheric temperature (°C)	Relative humidity (%)
0 – 5	618	36.2	52.4
5 – 10	607	36.3	52.1
10 – 15	539	36.3	52.0
15 – 20	526	36.7	51.3
20 – 25	517	36.8	51.3
25 – 30	459	36.8	50.9
30 – 35	450	36.9	50.1
35 – 40	430	36.9	49.8
40 – 45	411	36.9	48.4
45 – 50	409	37.1	48.4
50 – 55	343	37.2	48.2
55 – 60	336	37.4	48.2

In determining the average parts per million (ppm) CO_2 when DEEconverter was installed, the following were obtained:

$$Average\ (ppm) = \frac{Total\ parts\ per\ million}{Number\ of\ intervals} \tag{1}$$

$$= \frac{5645}{12} = 470\ ppm$$

The calculation shows the average parts per million (ppm) when DEEconverter was installed to the generator with an average of 470 ppm which shows a good atmospheric condition for the environment.

In determining the average air temperature (°C) when DEEconverter was installed. The following procedure was adopted:

$$Average\ air\ temperature = \frac{Sum\ of\ air\ temperature}{Number\ of\ intervals} \tag{2}$$

$$= \frac{36.2 + 36.3 + 36.3 + 36.7 + 36.8 + 36.8 + 36.9 + 36.9 + 36.9 + 37.1 + 37.2 + 37.4}{12}$$

$$= \frac{441.5}{12} = 36.8\ ^{o}C$$

The calculation shows the average air temperature when the DEEconverter was installed on the generator to be 36.8 °C. It shows an increase as against the ambient and/or environment air temperature of 35 °C.

In determining the average relative humidity (%) when DEEconverter was installed:

$$Average\ relative\ humidity = \frac{Sum\ of\ relative\ humidity}{Number\ of\ intervals} \tag{3}$$

$$= \frac{52.4 + 52.1 + 52.0 + 51.3 + 51.3 + 50.9 + 50.1 + 49.8 + 48.4 + 48.4 + 48.2 + 48.2}{12}$$

$$= \frac{603.1}{12} = 50.3\%$$

The derived result (50.3%) is the average relative humidity when DEEconverter was installed on the generator. This is a good result since it is within the recommended range of 30% - 60% recommended by ASHRAE (2016).

It should be noted that the average calculation of emission data derived from the DEEconverter, when installed to the diesel generator, gave significant results showing the effectiveness of the device in terms of reduction of emissions from the diesel generator. It should be noted also that the pollutant absorbing substances produced an effective absorption of emissions released by the diesel generator.

4. CONCLUSION

This study developed a diesel engine emission converter called DEEconverter, capable of purifying the exhaust of generating set. The mechanical device was designed with filtration and absorption chambers assembly parts. The result of the performance test conducted using the developed device, on generating set, was adequate. The equipment controlled the average air temperature and relative humidity within the recommended range of ASHRAE and greatly reduced the amount of carbon dioxide (CO_2) in parts per million released to the environment. The relevance of the DEEconverter is significant to a healthy environment.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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