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Evaluation of Scrubbers Efficiency for Air Quality Improvement near Gasoline-Powered Generators

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Abstract

The absence of regular power supply from the central grid of most developing countries has resulted in the use of independent small-scale electricity generators to meet the energy needs for sustained urbanization. The consequential effect of this is an increasing emission of exhaust gases leading to the degradation of the air quality. There are institutionalised methods aimed at controlling air quality on a global scale like afforestation, but there is a dearth of information about technologies to adopt on a small individual scale to protect air quality. This study compared and evaluated the efficiency of two different inorganic (Distilled water and Sodium Hydroxide (NaOH)) and organic (pig and poultry waste) scrubbing agents in removing pollutants from exhaust gas from gasoline-powered generators. Results showed 3 M NaOH had the highest removal efficiency for CO_2 (59.7%), CO (61.5%), HCHO (41.0%) and TVOC (41.3%) amongst the inorganic scrubber evaluated while 25 g/m^3 piggery waste showed higher efficiency (86.3%) in CO reduction, 15 g/m^3 poultry waste showed the highest efficiency (88%) for PM reduction, 35 g/cm^3 poultry showed the highest efficiency (70.4%) for CO_2 reduction, 35 g/m^3 piggery waste showed the highest removal efficiency (77.0%) for HCHO reduction and (72.4%) for TVOC reduction amongst the organic scrubbers evaluated. The effectiveness of NaOH solutions increased with concentration, however, an inverse relationship is recorded in particulate matter removal. The study concluded by applying theoretical chemical reactions to solving major environmental concerns while also presenting the feasibility of using agricultural waste for air quality management in the southwestern region of Nigeria.

Keywords: Air quality, Gasoline-powered Generator, Scrubbing Efficiency, Exhaust gases.

Introduction

Air pollution has emerged as one of the most pressing environmental challenges worldwide, largely due to industrialization, urbanization, and increasing energy demands. Among the significant contributors to air pollution is the widespread use of internal combustion engines (ICEs), particularly petrol engines, which emit harmful gases into the atmosphere. In southwestern Nigeria, individual households power generation is resulting in increasing exhaust gas generation whose major component gases are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), and other hydrocarbons, all of which contribute to air quality degradation (Lawal *et al.*, 2020). Nigeria, a country in the western hemisphere of Africa and specifically the southwestern region, is faced with a prominent challenge of insufficient and unreliable power supply (Oyedepo, 2014). This has resulted in the populace (private individuals, businesses, and industries) depending on stand-alone electricity generators as an alternative electricity source of which most of these engines are powered by fossil fuels such as petrol (gasoline) or diesel (Angelevska and Atanasova, 2017; Emovon *et al.*, 2018).

The phenomenon of individual power generation is not limited to Nigeria but to many developing countries, the reliance on generators has become a necessity due to unstable electricity supply, further exacerbating air quality deterioration. This problem is particularly evident in urban areas where generators serve as both primary and backup sources of electricity for homes, businesses, and industries. The growing dependence on these fossil fuel-powered engines has led to the release of pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), particulate matter (PM), and carbon dioxide (CO_2), all of which contribute to environmental and public health concerns (Angelevska and Atanasova, 2017; Cynthia and Chinaecherem, 2019).

According to Cynthia and Chinaecherem, (2019), air quality has noticeably declined due to the growing reliance on generators due to urbanization and rising energy needs, which has put significant pressure on urban ecosystems. (Ezetoha *et al.*, 2020; Adeegbe *et al.*, 2022) studied the effects of gasoline-generated emission (GGE) on animals and humans reporting increasing chances of health challenges. Khoa *et al.,* (2022) found several important pollutants discharged into the environment from generators that run on gasoline in different Nigerian homes and businesses. The negative effects of inhaled pollutants extend beyond the respiratory system, as pro-inflammatory cytokines—the inflammation mediators—travel through the bloodstream from the respiratory system to the entire body, leading to systemic inflammation (Cassee *et al.*, 2013).

Over the decades, engineers and environmental scientists have sought ways to mitigate the harmful effects of ICE emissions. The introduction of catalytic converters in the 1970s marked a significant advancement in emission control technology. These devices were initially designed to reduce CO and unburned hydrocarbons, which were the primary pollutants responsible for severe smog issues in major urban centers (Leach *et al.*, 2020). In the 1980s, the Three-Way Catalyst (TWC) was developed to further address NO_x emissions, making it a crucial component in modern emission control systems. Despite these advancements, petrol engines still emit substantial amounts of greenhouse gases and toxic pollutants, including CO_2 , CO, and NO_2 , which have been identified as major contributors to global warming and respiratory illnesses (Salvi *et al.,* 2017).

Given the increasing enforcement of global environmental regulations and the imposition of strict penalties on industries exceeding permissible emission limits, researchers have been exploring alternative methods for flue gas treatment. Among these, wet scrubbers have gained prominence as one of the most effective gas-cleaning technologies for reducing air pollution (Mahir and Manyele, 2023). Scrubbers function by introducing a liquid solvent, usually water or a chemical solution, into the exhaust stream to capture and neutralize pollutants. The absorption method, also known as the extraction process, is currently the most widely implemented approach in wet scrubbers (Rinprasertmeechai *et al.,* 2012). However, newer and more sophisticated absorption techniques, including Ionic Liquids (ILs), electrochemical conversion, photochemical, thermochemical, and biochemical methods, have been explored for improved exhaust gas treatment. These advanced methods utilize organic or organometallic catalysts for enhanced efficiency (Aghel *et al*., 2022). Nonetheless, challenges such as high costs, high energy consumption, and large-scale feasibility have hindered their widespread application.

Strategies have been proposed to mitigate the effect of emissions from the environment through natural activities such as afforestation Dontikurti *et al., (*2020), design of environmentally friendly engines Lott *et al., (*2024), and wet scrubbing Rakesh *et al.,* (2018) which has become one of the flue gas cleaning technologies Mahir and Manyele, (2023) but there is a dearth of information as to technologies that can be adopted for air quality management at the household level, thereby allowing the continued degradation of the air quality with little or no attempt for remediation at individual levels. Gas scrubbers have demonstrated high efficiency in particles removal, achieving over 99% reduction in SO_2 emissions across various engine loads. Additionally, elemental carbon reductions ranging from 50% to 81% have been reported, indicating significant improvement in the control of soot-related emissions (Winnes et al., 2020).

In recent years, the use of organic waste materials for emission control has gained significant attention due to their availability, cost-effectiveness, and eco-friendly nature. Agricultural by-products such as bagasse, rice chaff, corncobs, coconut husks, and water hyacinth fibers have demonstrated potential as solid sorbents for exhaust gas capture, owing to their porous structures and chemical compositions (Thawatchai, 2010). Similarly, livestock waste, particularly poultry and piggery waste, has been identified as a promising alternative for flue gas treatment due to its high nitrogen content and chemical reactivity. Poultry manure consists of excreta, feed residues, and bedding materials, with nitrogen primarily in the form of uric acid (70%) and undigested proteins (30%) (Dorivar *et al.*, 2008). Piggery waste, on the other hand, is rich in ammonia, a basic compound known to react effectively with acidic gases, making it a potential candidate for gas scrubbing applications (Fałtynowicz *et al.*, 2024*)*.

Despite the theoretical potential of poultry and piggery waste as organic scrubbers, there is limited empirical research on their practical application for petrol engine emission control. Most existing studies have focused on their use in agricultural applications, such as soil amendments and biogas production, with little emphasis on their efficiency in gas purification systems. Understanding their effectiveness in absorbing harmful exhaust emissions could open new pathways for cost-effective and sustainable emission control strategies. Hence, this study aims to evaluate the performance of poultry waste and piggery waste as organic scrubbers for a petrol engine while also comparing their effective with counterpart inorganic scrubbers. By assessing their gas absorption efficiency and comparing their effectiveness, this research seeks to explore sustainable and cost-effective emission control solutions. Findings from this study provide invaluable insights into the development of eco-friendly emission control technologies using readily available agricultural waste materials. By repurposing livestock waste for environmental benefits, this research supports circular economy principles and contributes to global efforts in reducing greenhouse gas emissions. Additionally, the adoption of organic scrubbers could serve as a low-cost alternative to conventional exhaust treatment technologies, particularly in regions where access to expensive catalytic converters is limited.

Methodology

Experimental setup

The research is conducted on a laboratory scale at the environmental engineering laboratory of the University of Ibadan, Nigeria. A moderate bubble column gas scrubbing unit was procured and designed to serve as the holding tank and interacting medium for the exhaust gas and the scrubbers. Other materials included two adaptors, one countertop water filter, one air valve, and galvanized steel pipes of different sizes: a 25.4 mm diameter pipe with lengths of 406.4 mm and 203.2 mm and a 44.45 mm diameter pipe with length 203.3 mm.

The exhaust gases are generated from the gasoline-powered engine operated at 3600 rpm at 50% loading. Twelve different scrubbing units were set up, six of the twelve treatments were organic scrubbing units while the remaining six were inorganic scrubbing units. The inorganic scrubbing units were divided into two groups comprising of distilled water and sodium hydroxide solutions.

Varied volumes (500, 750 and 1000 cm^3) of distilled water were used for the distilled water group, each volume constitute a separate scrubbing unit. For the NaOH solution, a fixed volume (1000 cm^3) but the varied concentration of NaOH solution (1 M, 2 M and 3 M in 1000 cm^3 of water respectively) was also studied similar to what was reported by Yoo *et al.*, (2012) and Lin and Chu, (2015) where aqueous solution of granular NaOH was dissolved in 500 ml of distilled water to have a 1 wt.% -5 wt.%.

The organic scrubbing agents were divided into two groups as well, Piggery waste and Poultry waste. Both poultry waste and piggery waste were treated with a 1M sodium hydroxide (NaOH) solution similar to (Thawatchai, 2010 ; Mardikios *et al.*, 2022). The masses of each of poultry and piggery waste were varied. 15 g, 25 g and 35 g were used each for the poultry and the piggery waste as compared with 15g used by Mardikios *et al., (*2022). The gas adoption was measured every second but readings were noted every minute. The efficiency of the scrubbing substance is measured by comparing the concentration of each of the identified pollutants before and after the exhaust gas has interacted with the scrubbers in the scrubbing unit. The schematics of the experimental setup are shown in Figure 1 and Figure 2.

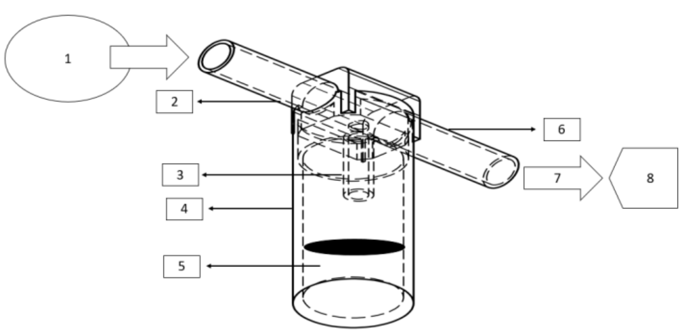

Figure 1: Set up of the scrubbing system
N.B. (1) Exhaust gas entrance (2) Inlet pipe (3) Downward delivery pipe (4) Countertop water filter container (5) Scrubbing solution (6) Outlet pipe (7)

Figure 2: Assembly of the scrubbing system with the generator

The exhaust gas from the petrol engine enters the countertop water filter and mixes with the scrubbing liquid. The pressure of the gas forces it out and this causes bubbling. The bubbling in the scrubbing liquid causes the mixing required for the study. The built pressure forced the scrubbed gas out through the outlet pipe where readings were taken. The efficiency of the scrubbing process is derived using Equation 1;

$$E = \frac{E_{in} - E_{out}}{E_{in}} \qquad (1)$$

Where E_{in} is the inlet emission concentration, E_{out} is the outlet emission concentration and E is the efficiency of scrubbing. The inlet and outlet emission concentration was measured using a 9-in-1 Air Quality Detector, model 2CO9, with input 5 VDC, 1 A and manufactured by Nobito (Shenzhen) Technology Co., LTD. The detector measures CO_2 in the range of 400– 6000 ppm,

CO in the range of 0-500 ppm, particulate matter in the range of 0-1000 µg/m^3, TVOC in the range of 0-2.0 mg/m^3, HCHO in the range of 0-0.6 mg/m^3. Gases flow into the scrubbing unit continuously without interruption. The initial data were taken before the gas was passed into the scrubbing liquid. One minute interval was observed for taking readings continuously for 20 minutes. Readings recorded were for CO_2, CO, Particulate matter (1.0, 2.5 and 10), TVOC, HCHO and pH.
The exhaust gases react with NaOH as seen in the equation (2 to 4) below;

$$2NaOH_{(aq)} + CO_{2(g)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)} \quad (2)$$

$$2NaOH_{(aq)} + CO_{(g)} \rightarrow Na_2CO_{3(aq)} + H_{2(g)} \quad (3)$$

$$2HCHO_{(g)} + NaOH_{(aq)} \rightarrow HCOONa_{(aq)} + CH_3OH_{(aq)} \quad (4)$$

The reactions of TVOCs depend on the type of compound in it. Ammonia is a major component in the organic constituents. It contributes significantly to the composition of the compounds. The reaction of the exhaust gases with NH_3 is seen in Equation (5 to 6) below though carbon monoxide does not react directly with ammonia.

$$CO_{2(g)} + NH_{3(aq)} \rightleftharpoons NH_4HCO_{3(aq)} \quad (5)$$

$$6HCHO_{(g)} + 4NH_{3(aq)} \rightarrow (CH_2)_6N_{4(aq)} + 6H_2O_{(l)} \quad (6)$$

Extracted data were subjected to a one-way ANOVA test to determine the significance of the scrubbing units' impact on the exhaust gases. Data were collected in triplicate and average values are presented with standard errors.

Results and Discussion

Removal of Carbon dioxide

The average progression in data recorded for carbon dioxide (CO_2) emissions and the standard error measured from the inorganic and organic scrubbers is presented in Figure 3. There was a reduction in the concentration of CO_2 gas as the volume-to-volume concentration of the scrubbing agents increased. For inorganic scrubbers, the CO_2 removal efficiency increased as the volume and concentration of scrubbers used increased. Among the NaOH solutions, the 3M concentration demonstrated the highest removal efficiency at 59.7%, significantly outperforming the 1M and 2M concentrations, which achieved efficiencies of 52.9% and 57.6%, respectively. Water (H_2O) demonstrated much lower removal efficiencies across all volumes tested. At 500 ml, the removal efficiency was 34.6%, which increased to 41.2% at 750 ml and 44.7% 1000 ml. The higher the concentration of the hydroxide ions, the higher the efficiency of reducing the carbon dioxide from the exhaust presenting NaOH as a more effective inorganic scrubber than distilled water for CO_2 removal. Similarly, increasing the scrubbing agent masses from 15 g to 35 g generally improved CO_2 removal efficiency, although the rate of improvement varied between the waste types and showed signs of diminishing returns at higher concentrations. The trend analysis of the experimental data revealed that as the masses of poultry and piggery waste increased, CO_2 removal efficiency also increased. At 15 g, piggery waste with efficiency of 30.8% demonstrated slightly higher CO_2 removal efficiency than poultry waste with 25%, suggesting an initial reactive effectiveness in capturing CO_2. At 25 g, both waste types exhibited comparable efficiencies, with piggery waste at 61.1% while poultry waste at 25g has an efficiency of 53.1% indicating that increasing the mass of scrubbing material contributed to better CO_2 absorption. By 35 g, poultry waste efficiency of 70.4% outperformed piggery waste of 67.9%, likely due to its higher alkalinity and enhanced reactive surface area, which facilitated greater CO_2 absorption.

Although increasing the mass of the scrubbing agents generally resulted in better CO_2 removal, the rate of improvement was not linear. The difference in efficiency between 15 g and 25 g was more significant than between 25 g and 35 g, suggesting that beyond a certain threshold, the additional scrubbing material showed diminishing returns. At the highest concentration of 35g, poultry waste achieved the highest CO_2 removal efficiency. However, the diminishing rate of efficiency gain suggests that an optimal concentration exists beyond which increasing the amount of scrubbing material does not yield significant benefits. This plateau effect is likely due to the limited interaction between the gas and the liquid medium or saturation of active absorption sites. The One-way ANOVA test of the scrubbing agents as represented in Table 1 showed that there was a significant change in the CO_2. The $F_{computed}$ of 24.49 is greater than the $F_{critical}$ of 1.78.

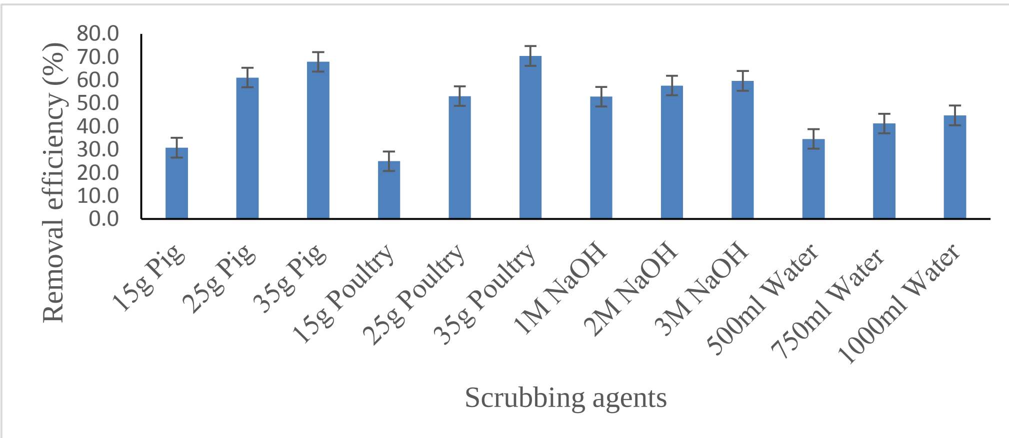

Figure 3: Removal efficiency (%) of CO_2

Table 1: Results of One-way Anova Test

No	Exhaust parameter	F-computed	F-critical
1	CO_2	24.49	1.78
2	CO	31.10	1.78
3	pH	0.19	4.30
4	PM	2281.19	2.12
5	HCHO	20.94	1.78
6	TVOC	19.29	1.78

A 70.4 % CO_2 removal efficiency from the exhaust gas of a Gasoline-powered generator was achieved in this study when 35 g of poultry waste was used as the scrubbing agent. The highest result obtained for inorganic scrubbing agents was by 3 M of NaOH and it is lower when compared to the maximum of 67.95 % obtained by Arifin *et al., (*2022) who used a larger volume (5 litres) compared to the 1 litre used in this experiment. Also, in an experiment by Shaisundaram *et al., (*2018) a reduction in percentage composition was observed from 4% to 3.608% and from 9.2% to 7.958% while using Lithium hydroxide, calcium hydroxide and silicon dioxide. In a similar study by Kumar *et al., (*2021) using monoethanolamine (MEA), N, N-dimethylethanolamine (DMEA) and chilled ammonia as scrubbing agents to capture CO_2, MEA, DMEA, chilled ammonia had efficiencies of 90.95%, 57.66% and 80.08% respectively. These efficiencies are higher except for chilled ammonia. These higher efficiencies could be attributed to the temperature regulation of the scrubber used. Though chilled ammonia is used. Also, the removal efficiency in this study is compared to a study by Kumar *et al., (*2021) whose efficiency was 96.2% when multi-substrate agricultural waste-derived activated carbon was used for the scrubbing. The results of similar experiments conducted by Arifin *al., (*2022) showed an average efficiency of 67.96% which is quite lower when compared to the results obtained in this study. Arifin *al.*, *(*2022) solely used NaOH which could be a major factor in the reduced efficiency as organic matter consists of other substances which have an affinity for acidic gases. The increased residence time and brine mixed with ammonium hydroxide could be the causative agent for the higher efficiency. Though the efficiency of 70.4% is lower when compared, a higher number of the gases were able to be scrubbed and not released to the atmosphere.

Removal of carbon monoxide

A similar trend was observed for CO removal in this study by the scrubbing agents as seen for CO_2 and this was presented in Figure 4 for both scrubbing categories. As the volume of water increased, the removal efficiency of CO from the exhaust gas increased and as the concentration of NaOH increased, the CO removal efficiency also increased. The removal efficiency for 500 ml, 750 ml and 1000 ml of water was 12.4%, 31.5% and 36.5% respectively. The results from the organic scrubbers indicated that the removal efficiency of CO also followed a trend similar to that of CO_2 , with increasing concentrations of scrubbing agents leading to higher removal efficiencies. However, the rate of increase in efficiency was more pronounced for CO removal than for CO_2 , suggesting that the chemical interactions between CO and the scrubbing agents were more effective. At 15 g of scrubbing agent, piggery waste demonstrated slightly higher CO removal efficiency than poultry waste. This trend was similar to the observations for CO_2 removal, indicating that piggery waste had an initially higher reactivity with CO. However, as the mass of the scrubbing agents increased to 25 g and 35 g, poultry waste exhibited superior CO removal efficiency. This suggests that the increased surface area and higher alkalinity of poultry waste played a more significant role in capturing CO molecules at higher concentrations. The trend showed that the removal efficiency of CO increased consistently with the increasing mass of the scrubbing agents. However, like CO_2 , the rate of improvement was not linear, with the most significant efficiency gain occurring between 15g and 25g. Beyond this concentration, the efficiency increase became less pronounced, indicating that additional scrubbing does not result in commensurate CO removal.

From Figure 4, it is observed that the highest efficiency of 86.3% is from 25 g of piggery waste. The 25g piggery waste setup gave the highest CO scrubbing (86.3 %) in this study. While 3 M NaOH had the highest removal efficiency of 61.5% for the inorganic scrubbing agents for CO scrubbing, which is higher than the efficiency of 46.92% obtained by (Arifin *al.,* 2022) who performed a similar experiment. This notable change could be attributed to the higher concentration of (1 M, 2 M and 3 M) used as compared to the lower concentrations (0.05 M, 0.10 M, 0.15 M) used by Arifin *al.*, *(*2022). In a similar experiment by Wang *et al*., (2019), the removal efficiency of CO was 50.4% when using Fe^{3+} and 35.2% when using Cu^{2+} at a high concentration of 600 ppm for carbon monoxide. These efficiencies are lower when compared with 3 M NaOH used in this study, the low efficiency could be attributed to the higher number of ions in the Fenton-like reduction systems, and the high concentration of carbon monoxide at about 600 ppm was a factor which contributed to the reduction of its efficiency. When subjected to statistical analysis, the $F_{statistic}$ value was greater than the $F_{critical}$ which is 2.15. Also, the P-value calculated is 6.7×10^{-19} which was less than the P-value of 0.05 chosen. This led to the conclusion that there was a significant reduction in the value of CO removed based on this study.

In an experiment by Arifin *al., (*2022), the average removal efficiency for CO is 46.92%. This is lower when compared with that of the organic scrubbing agents. Organic scrubbing agents used in this research showed a higher performance than the sole NaOH used by Arifin *al., (*2022). In a similar experiment by (Wang *et al*., 2019) the efficiency of scrubbing ranges between 74.5% and 95.1% which is quite similar to this experiment. The cause for higher efficiencies could be attributed to the Fenton-like material used. Another experiment on particulate matter by Zhou *et al., (*2021) gave efficiencies between 90 – 98%. This was closer to the values obtained in this experiment for NaOH in scrubbing particulate matter. The higher efficiency of their study can be attributed to the apparatus used which included a spray chamber for removing particulate matter. These efficiencies by organic scrubbing agents are very much closer though Zhou *et al.,(*2021) had probably a higher but on overall average this research his more efficient. Similarly, in an experiment by Lee *et al., (*2012), the removal efficiency for particulate matter was found to be around 55% - 62 % for particles below 1 µm. This low efficiency when compared to this study is attributed to the size of the particulate matter as the efficiency of removal of particulate matter increased as the size increased. Also, Sun *et al., (*2020), recorded a removal efficiency for particulate matter of 94.72% in a similar experiment, this slightly higher efficiency was due to the ammonia solution used and a higher flow rate (210 L/h). Though the efficiency recorded from this study was lower, it still proved NaOH can be used for scrubbing particulate matter. This study aligns with sustainable development goals (11) for sustainable cities and communities as it focuses on removal of harmful gases from petrol exhaust which contribute to urban air pollution. The One-way ANOVA test of the scrubbing agents as presented in Table 1 showed that there was a significant change in the CO. The $F_{computed}$ of 31.10 is greater than the $F_{critical}$ of 1.78.

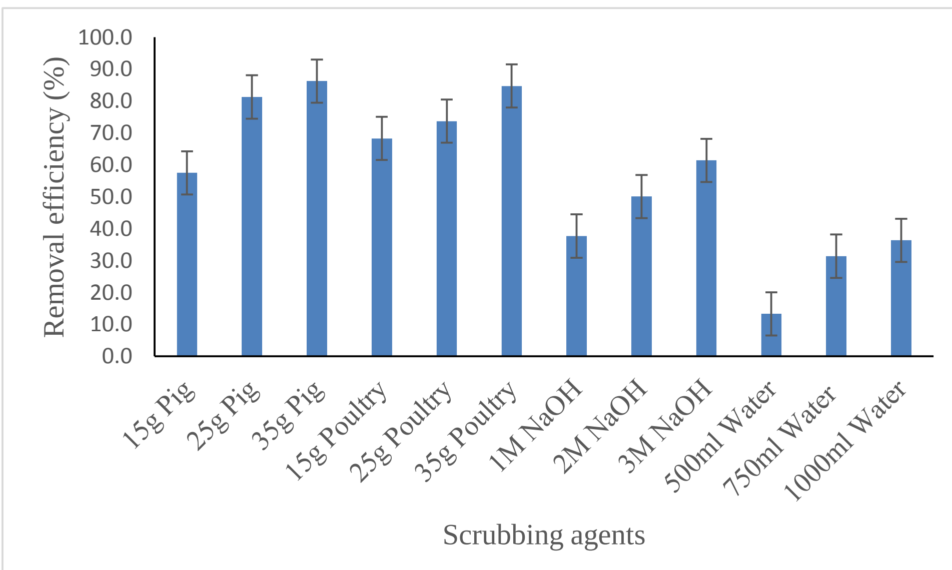

Figure 4: Removal efficiency of CO

pH of the scrubbing agents

The results of the pH values of the inorganic scrubbers were analyzed using One-way ANOVA with a probability level of 95%. It was observed that the $F_{statistics}$ was 0.19, the $F_{critical}$ was 4.3. The $F_{computed}$ is less than the $F_{critical}$, these values denoted that there was no significant difference in the changes in pH values. However, piggery waste maintained a higher pH level compared to poultry waste, which contributed to its stronger alkaline properties. The higher alkalinity of piggery waste solutions created a more favourable medium for the absorption of acidic gases like CO_2 , enhancing its performance as a scrubbing agent at lower concentrations. However, poultry waste, despite having a slightly lower pH, exhibited higher removal efficiencies at higher concentrations. As the mass of the scrubbing agents increased, the pH levels of the solutions also showed a slight increase, further improving pollutant absorption. This correlation suggests that maintaining an optimal pH range could enhance the effectiveness of organic scrubbing materials.

A major source of the increased basicity of these solutions was the adoption of particulate matter in the solutions. 1 M NaOH absorbed the highest particulate matter followed by 2 M and then 3 M, explaining the basicity of the solutions. It was also seen that the absorption of particulate matter directly correlated to the volume in distilled water and hence the pH of the resulting solution. The amount of hydroxide ions in 3 M NaOH was more than other scrubbing agents, these hydroxide ions have a higher affinity for acidic compounds and as such absorb more of the acidic components of the exhaust gas. In a report by (Singh *et al.*, 2016), it was noted that particulate matter was a cause of alkalinity when absorbed by water. This could also be the case as all the scrubbing agents absorbed particulate matter. The reaction between sodium hydroxide and carbon dioxide gave sodium tri oxo carbonate (iv) salt which is basic. These factors contributed to the increased basicity of the solutions. The highest pH before scrubbing was 35g piggery waste with a pH of 12.26, (Figure 5) followed by 25g piggery waste. The lowest pH was in 15g and 25g of poultry waste. The difference in pH could be traced to the various composition of the solutions. In comparison with inorganic scrubbers, organic scrubbers tend to be more acidic showing a considerable absorption of carbon monoxide and carbon dioxide.

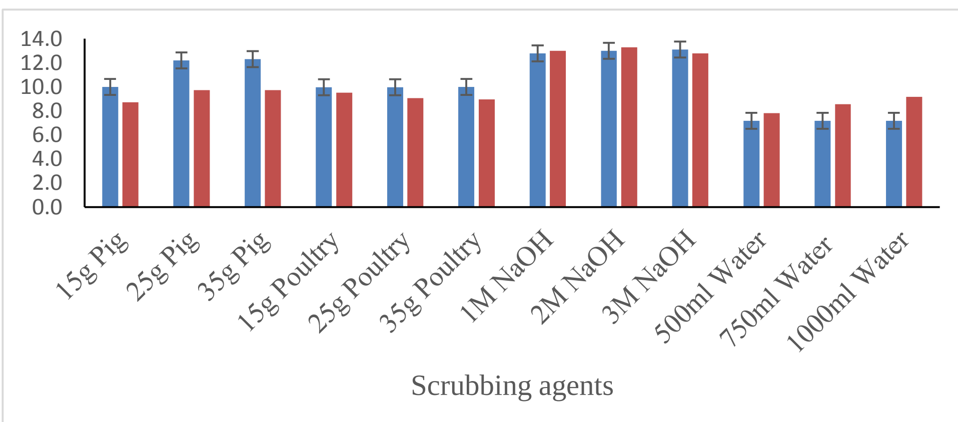

Figure 5: pH of the scrubbing agents

Removal of particulate matter

The removal efficiency for the particulate matter was summarized in Figure 6 for inorganic scrubbers and organic scrubbers. As the volume of water increased, the rate of absorption also increased, this increase was attributed to a larger amount of water molecules ready to absorb the particulate matter. For NaOH solutions, however, the trend showed a decrease in the absorption capacity as the concentration increased. Similarly, 15g poultry waste has the highest efficiency of 88% which is closely followed by 25g piggery waste with an efficiency of 87.2%. The least is 35g poultry waste with an efficiency of 83%. The experimental results showed that both poultry and piggery waste scrubbing agents were effective in reducing PM concentrations, with removal efficiencies decreasing as the mass of the scrubbing agent increased. At the lowest concentration of 15g, poultry waste exhibited slightly higher PM removal efficiency than piggery waste. As the mass of the scrubbing agent increased to 25g and 35g, piggery waste demonstrated a greater increase in PM removal efficiency compared to poultry waste. The One-way ANOVA test of the scrubbing agents presented in Table 1 showed that there was a significant change in the particulate matter. The $F_{computed}$ of 2281.19 is greater than the $F_{critical}$ of 2.12.

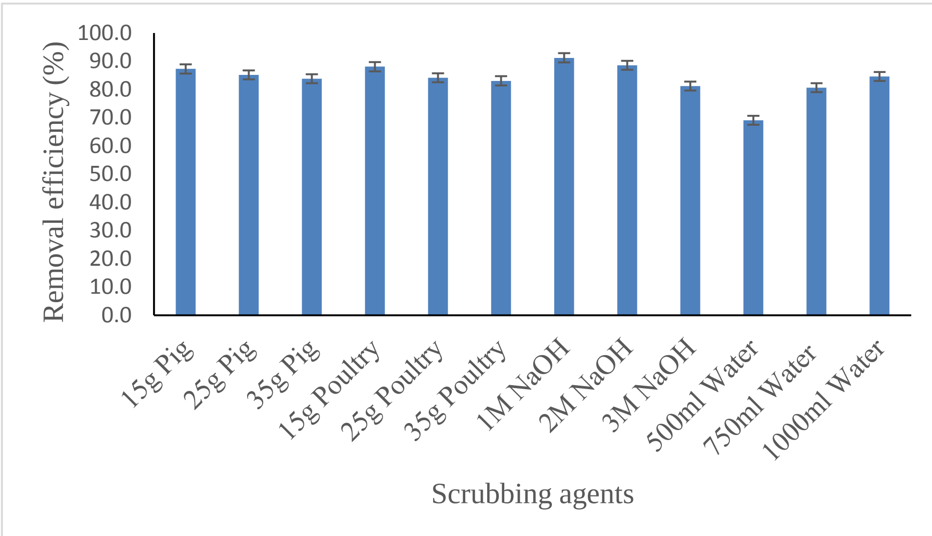

Figure 6: Removal efficiency (%) of particulate matter

Removal of Formaldehyde (HCHO)

Figure 7 summarized the removal efficiency for Formaldehyde. It was observed that 3 M NaOH has the highest efficiency among the inorganic scrubbing agents while 500 ml of water has the lowest efficiency. The efficiency was at a maximum (41 %) of 3 M NaOH and at its lowest (7.1 %) for 500 ml of water. There was an increase in efficiency as the volume of water increased, this trend was also observed as the concentration of NaOH increased. Formaldehyde is known to be a weak acid and hence would have an affinity for NaOH solutions. Figure 11 showed the efficiency of the organic scrubbing agents. 35g piggery waste has an efficiency of 77% which is the highest among the organic scrubbers followed by 35g of poultry waste with an efficiency of 72.5%. Both poultry and piggery waste scrubbing agents were effective in reducing formaldehyde concentrations, with removal efficiencies improving as the mass of the scrubbing agent increased. At the lowest concentration of 15g, poultry waste exhibited fairly the same formaldehyde removal efficiency as piggery waste. However, as the mass of the scrubbing agents increased to 25g and 35g, piggery waste demonstrated superior formaldehyde removal efficiency. The trend analysis showed that increasing the scrubbing agent concentration mass led to higher formaldehyde removal efficiency, but with diminishing returns beyond 25g. This indicates that while higher concentrations of organic scrubbing materials improve formaldehyde capture, a saturation point exists where additional mass does not significantly enhance removal performance.

The removal efficiencies for HCHO in this study were lower when compared to the study by Xie *et al., (*2019) whose efficiencies were 98.3% and 96.5%. The high performance observed in their study may be attributed to the wide range of chemicals used in conjunction with the UV/PMS process. The chemicals used include sodium chloride, sodium carbonate, ozone and 5,5-dimethyl-1-pyrroline. In contrast, the present study uses only Sodium Hydroxide and organic wastes as scrubbers. Although, the maximum efficiency of 77% was obtained in this study, this still represents a high percentage of HCHO being removed. This shows that organic wastes are better source of scrubbing formaldehyde. Furthermore, a positive correlation between quantity of organic wastes and scrubbing efficiency was observed, indicating that increased quantity and active sites contributed to improved scrubbing efficiency.

Hasan *et al.,(*2016) achieved a complete (100%) removal of formaldehyde using a prototype 3-zone catalyst at temperatures greater than 400°C. Their results highlighted the influence of high retention time on oxidation kinetics. The prolonged contact time in their reactor enhanced mass transfer and catalytic reaction rates. However, such high-temperature systems may involve greater energy input compared to the present study. Similarly, Premkumar and Balaji, (2021) observed that the HCHO content was reduced by 14%. This is quite lower when compared to 1 M, 2 M and 3 M NaOH solutions in this study. The low efficiencies in their study might be attributed to the varying brake power studied in their set-up. Yu *et al*., (2013) recorded a removal efficiency of 83% following the impregnation treatment of Na-CH in NaOH solution. While the scrubbing efficiency achieved by Yu *et al.*, (2013) was slightly higher, it requires the modification of chemicals. In contrast, the current study indicated that a considerable reduction in the harmful hydrocarbons which might be released to the environment can be achieved using comparatively simpler and environmental friendly chemicals. The analysis results for the scrubbing agents using One-way ANOVA in Table 1 shows that the $F_{computed}$ value is 20.94 which is greater than the $F_{critical}$ which is 1.78. This leads to a conclusion that there is a significant effect of reducing the value of HCHO.

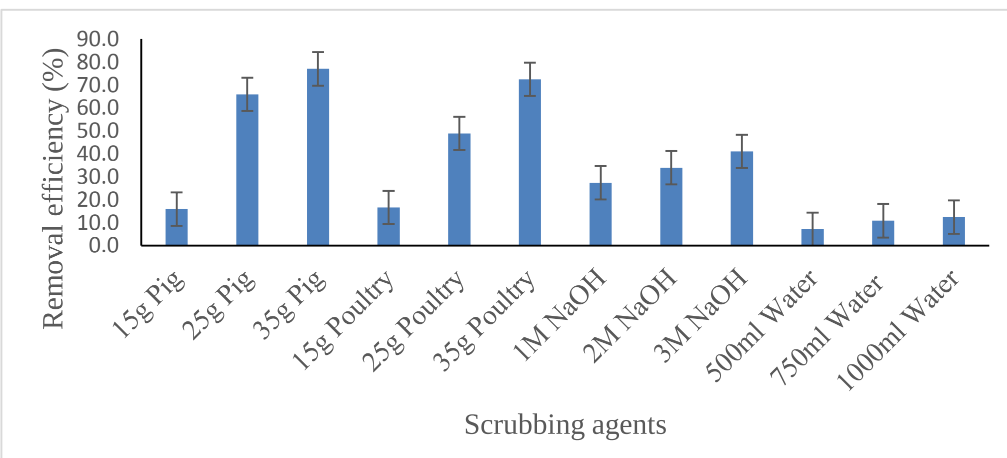

Figure 7: Removal efficiency (%) of HCHO with scrubbing agents

Removal of Total Volatile Organic Compound (TVOC)

The removal efficiency of total volatile organic compounds by inorganic scrubbing agents is presented in Figure 8. The 3 M NaOH had the highest scrubbing efficiency of 41.3% and 500 ml of water had the lowest efficiency of 6.2%. Looking at the trend, an increase in the volume of water leads to an increase in absorption of TVOC. Also, an increase in the concentration of NaOH led to an increase in the absorption of TVOC. TVOC may be acidic or basic, the ones from the exhaust gases are likely to be acidic as this indicates why the exhaust gas had an affinity for NaOH solutions and this led to higher absorption by NaOH solutions. Similarly, Figure 13 shows that 35g piggery waste has the highest efficiency of 72.5% which is closely followed by 69.8% of 35g poultry waste. The least efficient is 15g poultry waste with an efficiency of 21.2%. Higher masses of the organic solutions show a higher scrubbing efficiency. This trend remained consistent at 25g and 35g, with piggery waste outperforming poultry waste in TVOC removal at all concentrations. The superior performance of piggery waste in TVOC removal may be attributed to its enhanced adsorption capacity and higher chemical reactivity, which allowed for more efficient trapping and breakdown of volatile organic compounds. The trend analysis indicated that increasing the mass of the scrubbing agent led to higher TVOC removal efficiency, but the rate of improvement declined beyond 25g.

Cheng *et al., (*2021) achieved an efficiency of 80% while scrubbing volatile organic compounds, this efficiency is higher than the maximum of 72.5% gotten from this experiment. The higher efficiency could be attributed to the higher residence time used in the experiment. Removal efficiencies between 35% and 85% due to the G/L (gas/liquid) ratio used by Ghoreyshi *et al., (*2014). As the G/L ratio increased, the removal efficiency increased. The efficiencies in this study are lower when compared to the study by Kumar *et al., (*2021) whose efficiencies were about 96%. This observable difference can be attributed to the wide range of chemicals used with the UV/PMS process. The chemicals used include sodium chloride, sodium carbonate, ozone and 5,5-dimethyl-1-pyrroline. A reduction of over 40% TVOC means that a significant amount of volatile organic compounds would be removed from the environment which if not removed, poses a significant risk to the environment.

The findings in this investigation are also less than those in the study Xie *et al., (*2019), which had efficiencies of 98.3% and 96.5%, respectively. This noticeable discrepancy can be ascribed to the extensive usage of chemicals in the UV/PMS process. Ozone, sodium carbonate, sodium chloride, and 5,5-dimethyl-1-pyrroline are among the substances utilized. The analysis results for the scrubbing agents using One-way ANOVA in Table 1 shows that the $F_{computed}$ value is 19.29 which is greater than the $F_{critical}$ which is 1.78. The analysis results of both the inorganic and the organic scrubbing agents by the One-way ANOVA program led to a conclusion that there is a significant effect of reducing the value of TVOC.

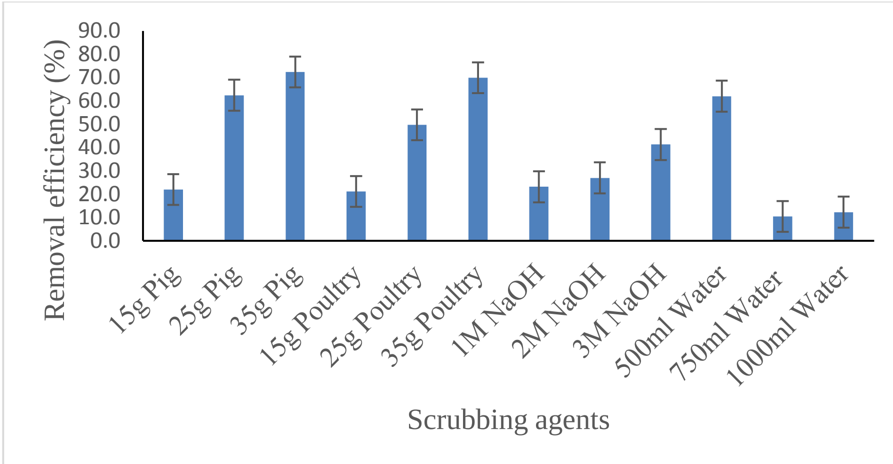

Figure 8: Removal efficiency (%) of TVOC

Conclusion and Recommendations

The earth remains the only planet that has been sufficiently inhabited by human and hence, it has to be preserved. The findings from this study showed that the concentrations of pollutants, such as carbon dioxide (CO_2), carbon monoxide (CO), particulate matter, formaldehyde (HCHO), and total volatile organic compounds (TVOC), were considerably lowered when the exhaust gas is passed through both the inorganic and organic scrubbers. This by implication means that lower concentration of the pollutant is introduced into the environment with the inclusion of the scrubbing unit. While the inorganic scrubbers showed prospects based on simple chemical reactions and explanations, the organic scrubbers displayed more prominent prospects for air quality protection in their use as scrubbing agents.

This result does not only provide a viable alternative for carbon sequestration but provided a novelty in the waste management and circular economy ecosystem. This study showed that agricultural waste can be used to trap and scrub potential air pollutants from the exhaust generated by gasoline-powered generators with little or no technicality. This is an eye opener and a novel discovery that can be developed to be incorporated as a small-scale technology for the protection of the air ecosystem from the incessant ejection of exhaust from gasoline-powered engines that is necessitated by the need to bridge the energy gap in the southwestern region of Nigeria. This experiment being on a laboratory scale, gave a performance that showed prospects in improving environmental quality, however, further study should be undertaking at optimizing the quantity of scrubbing device required to remove known quantity of pollutant as well as scaling up the experiment. Other parameters should also be factors into the experiment like the use of the resulting compound formed after the scrubbing and the best method to discharge such. This will allow for the continued generation of energy with minimal effect on the environment thereby assuring environmental protection from the use of gasoline-powered generators in southwestern Nigeria.

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