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EFFICIENCY OF COMBINED USE OF CHARCOAL AND ACTIVATED CARBON FROM COCONUT SHELLS IN THE PURIFICATION OF GENERATOR EXHAUST FUMES

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ABSTRACT

Studies have shown that exhaust fumes contain many known or suspected carcinogens. This study reports the use and effectiveness of granular activated carbon and charcoal made from agricultural waste (coconut shell) for the removal of contaminants from gasoline powered generator exhaust fumes. In order to treat the exhaust from gasoline powered generator, a reactor referred to as adsorption column was used, with the gas flow being vertical through the adsorbents (charcoal and activated carbon) that were placed inside the reactor. Granulated activated carbon (200, 400, 600, 800, and 1000 g) were placed so that the exhaust from the generator could pass through it freely and also prevent the samples from falling out. The gas after the treatment was let into the gas analyzer to analyze the proportions of the gas components. This was done until the optimum quantity of activated which produced the best result of the filtered exhaust was obtained. These procedures were repeated using charcoal. 800 g of charcoal and activated carbon of mass 1000 g gave the best treatment, these were then combined as pre-filter and filter respectively in the adsorption column. Concentrations of the exhaust gas were taken at 5 min interval for a period of 25 min by using a gas analyzer, and the useful life was determined to be 20 min. Charcoal and activated carbon made from coconut shell resulted to percentage pollutant removal by 34.1% HC, 70.4% NOx, 66.1% CO and 52.5% CO_2 from a gasoline powered generator exhaust fumes. The renewal of the adsorbent can be done by re-activation.

Keywords: Adsorption Column, Pollutants, Activated Carbon, Charcoal.

INTRODUCTION

Air pollution is certainly not a new phenomenon. Indoor pollution was probably experienced by the inhabitants of caves and of primitive houses, which had no or insufficient evacuation of fumes, and natural phenomena like volcanic eruptions and the accidental or voluntary burning of woods and forests have certainly contributed to the emission of pollutants into the air since time immemorial (reference).

There is little doubt, however, that air pollution has increased recently; the pollution of air nears certain industrial plants and in large cities is one of the alterations to human existence brought about by industrialization. Rene (1965) observed that, although air pollution is an old phenomenon, the introduction of more of the same and new pollutants on a large scale has recently transformed it into an important health problem. Trends in estimated emissions of some of the most important air pollutants have been calculated for the world (UNEP Environmental Data Report, 1989) and for individual countries (Bocola *et al*., 1989). These show that air pollution has become a planetary problem, and there is now no area of the earth that has been spared the presence and consequences of air pollution, as pollutants can cause damage far away from their point of emission into the atmosphere (Derwent *et al*., 1988).

One major environmental hazard associated with globalization is the influx of electric power generators, commonly called 'generators' in Nigeria. Due to incessant cut in power supply in Nigeria, most homes and industries resort to the use of these electric power generators. These generators are major sources of noise and air pollution to the environment. Many industries as well as many homes use them for several hours as an alternative source of power supply, despite the fact that they are only meant to be backups for electricity. Also, apart from the nuisance it constitutes as a result of noise in the neighbourhood, many Nigerians have lost their lives from the use of electric power generators either through an electrical shock or the inhalation of generator fumes which often contain high concentrations of carbon monoxide. CO_2 is also a by-product and it is known as the most important cause of global warming. The rapid development of industrial technologies has significantly increased the concentration of greenhouse gases such as CO_2, CH_4, HFCs, and PFCs in the atmosphere.

The greenhouse effect of these gases lead to environmental pollution, exacerbates global warming, raises ocean water levels, and affects the balance of the ecosystem (Figueroa *et al*., 2008; Yang *et al*., 2008). Global warming is caused by the emission of greenhouse gases. 72% of the totally emitted greenhouse gases is carbon dioxide, 18% methane and 9% nitrous oxide.

Nitrogen dioxide is the predominant form from the point of atmospheric significance on the local, regional and global scales as well as for human health (Bocola *et al*., 1989; Derwent, 1988). In the lower atmosphere, NO_x is involved in the photochemical production of ozone and with sulphur oxides (SO_x), which contribute to acidic wet and dry deposition (IARC Monograph 1985). Several researchers have implicated electric generator engines in the emission of large amounts of gaseous and particulate pollutants into the environment where they are used (Geiss *et al*., 2010; Wu *et al*., 2010; Avino *et al*., 2011).

Exhaust pollutants result to increased infant mortality (Gosline *et al*., 2004), acute heart attacks (Peters *et al*., 2004), chronic deficits in lung development of children aged 10-18 years (Gaudeman *et al*., 2004), many known or suspected carcinogen (Okoro *et al*., 2006) and ovarian cancer (Guo *et al*. 2004).This study carried out reduction in the level of pollutants emitted by the development and testing of filters for gasoline generator exhaust fumes by coconut shells which is cheap and readily available.

MATERIALS AND METHODS

Procurement of coconut shell

The coconut shells were collected from Gaskiya Road by Agoro Round-about area, Zaria, Kaduna State, Nigeria.

Sample treatment:

The method of sample treatment adopted by Mozammel *et al*. (2002), Itodo *et al*. (2009a and b) was used. The coconut shell materials were crushed manually to small chips of approximately equal sizes of 4 cm. The coconut shells were washed with enough clean water to remove surface impurities; these were then placed inside an oven and heated at 105^0C for 24 h in order to remove the moisture content. The dried coconut shells were then placed in airtight plastic bags to prevent re-absorption of moisture from the atmospheric air.

Carbonization of Coconut Shells

The pre-treated sample was loaded in a heat treatment furnace (serial no: G052284K) and heated up to a carbonization temperature of 600^0C without ash formation, and was then held for 2 h at the carbonization temperature under N_2 gas flow in order to create an inert atmosphere in the furnace. As carbonization time was reached, the furnace heating source was switched off and allowed to cool with nitrogen gas still flowing. The carbonized samples were further cooled to room temperature. The carbonized samples were crushed and sieved to obtain particle sizes greater than 4.75 mm.

Experimental setup

Chemical activation was performed with phosphoric acid (H_3PO_4). A 200 g amount of the coconut shell char was separated from the bulk and then 10 g each was measured into 20 different rubber containers. The sample in each container was then impregnated with the prepared solution of 1M phosphoric acid in order to obtain the desired ratio (1:1 -1:2) of phosphoric acid and allowed to soak for 24 h in the laboratory. Then, the impregnated chars were packed into small ceramic crucibles and placed inside a heat treatment furnace and heated to the desired temperatures ($400\text{-}700^0$C). For each of these temperatures, one sample of each impregnation ratio was withdrawn at predetermined time interval (5-10 mins). The activated carbon obtained was removed from the heat treatment furnace. After cooling, the activated carbon was repeatedly washed with distilled water in order to remove surface ash and residual acid (Rahman *et al*., 2005). The activated carbon obtained was then dried at 100°C for 1 h (Odebunmi *et al*., 2001).

Characterization of Activated Carbon

The surface area was determined by iodine value test which is a relative indicator of porosity in an activated carbon.

Some portion each of the 20 sets of produced activated carbon were collected and pounded followed by sieving with a 4.75mm sieve. The less than 4.75mm sample were stored in airtight containers and characterized as follows:

1. **Iodine value of the activated carbon (I.V)**

The iodine number is the amount of iodine, in milligrams, adsorbed per gram of carbon when the equilibrium concentration of Iodine is 0.02 M. It (Gergova *et al*., 1994), and measures the porosity for pores with dimensions between 1.0 - 1.5 nm (Collin *et al*., 2006). Iodine value determination was carried out by the method of Association of Analytical Chemist (1975).

Procedure for iodine value test

Activated carbon sample of 1 g was placed in a 250 ml conical flask followed by 30 ml Hanus solution and the flask stopper. The content was mixed and allowed to settle for exactly 30 min. The solution was then titrated against 0.1N $Na_2S_2O_3$ until it became light yellow. 2 ml of 1% starch indicator was then added and the titration continued until the blue colour disappeared. A blank determination was also carried out under the same conditions and the I.V calculated as thus;

$$\text{I.V} = (\text{B} - \text{S}) \times 126.9 \times \frac{\text{N}}{\text{Weight of sample}} \qquad (1)$$

Where;

$\text{B} = \text{blank titre}$
$\text{S} = \text{sample titre}$
$\text{N} = \text{normality } Na_2S_2O_3$
$\text{W} = \text{weight of sample}$

2. Bulk density: This was determined by the formula 2 below

$$\text{Bulk density} = \frac{W_2 - W_1}{V} \qquad (2)$$

Where:

$W_2 = \text{weight of bottle} + \text{sample}$
$W_1 = \text{weight of empty bottle}$
$V = \text{volume of sample}$

Design Methodology for the Adsorption Column

The adsorption column is 1 m long, 9 cm diameter pipe made from sheet metal in which the purification of the gasoline powered generator exhaust fumes took place. The inlet was designed in a way that it allowed fumes from the generator to gain entrance into the adsorption column where the filtration takes place.

The adsorption column consists of two separate layers of wire mesh above the base of the reactor on which charcoal and activated carbon were placed respectively. The charcoal served as the pre-filter while the main filter was the activated carbon. Different quantities of charcoal and activated carbon were varied until the optimum quantities were obtained individually and then combined.

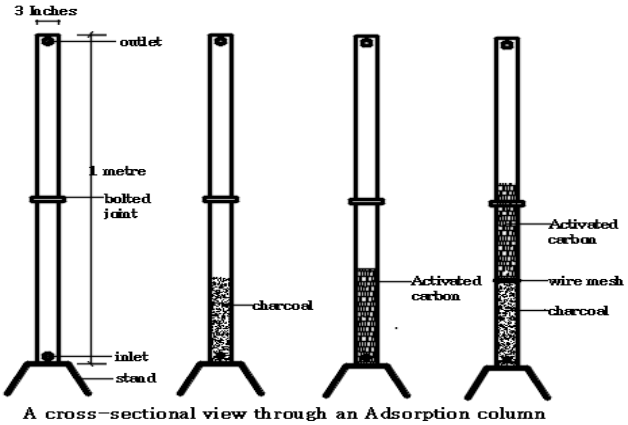


Fig 1: Schematic representation of the adsorption column

Experimental Procedure

The gasoline generator exhaust used in the experiment was from a Gasoline powered generator (Tiger TG 1150). The gasoline powered generator was treated at no load in order to know the actual concentration of the pollutants present in the exhaust fumes. The gasoline powered generator was switched on and allowed to run for 60 min to warm the engine. Most of the exhaust was let off to the atmosphere and only a part of the exhaust was taken for the analysis in order not to damage the gas analyzer. The gas analyzer (NHA-506EN NANHUA) was switched on and allowed to

boot for 10 min (standard time). The analyzer was then connected by a probe to the adsorption column (reactor) which was in turn connected to the exhaust pipe for some minutes to test for the concentration of the pollutants from the exhaust fumes without any adsorbents present (this was used as the control). After which the result obtained from the analyzer was read and recorded.

3000 g of the granulated activated carbon was divided into varying weights (200, 400, 600, 800, and 1000 g) using a weighing scale. The individual samples of activated carbon were placed on a wire mesh already placed in the adsorption column in such a way that the activated carbon were not compacted; so that the exhaust from the generator could pass through easily to prevent obstruction of flow and also to prevent the samples from falling out. The gas obtained after the treatment in the reactor (adsorption column) was let into the gas analyzer to analyze the proportions of the gas components. The concentration of the exhaust was then read and recorded. This was repeated until the optimum quantity of the activated carbon which produced the best result of the filtered exhaust was obtained. These procedures were repeated all over using charcoal.

Plate 1: Experimental setup

The quantity of activated carbon that gave the best result was then combined with charcoal in varying quantities (200, 400, 600, 800 and 1000 g) as filter and pre-filter respectively in order to determine if a better result could be obtained. The adsorption capacity of the adsorbents were then determined by running the gasoline powered generator while reading were taken at 5 min interval on the gas analyzer.

RESULTS AND DISCUSSIONS

Characteristics of the Activated Carbon Obtained

Iodine value

The experiment revealed that the iodine value of the activated carbon made from coconut shell was 568.512 mg/g.

Bulk Density

The bulk density of the coconut shell activated carbon produced at 400^0C, 10 mins and 1:1 impregnation ratio was 0.6402 g/cm^3. This value could be due to the fact that the parameter depends largely on the starting raw material (coconut shells) as well as the temperature and time of activation. It was observed that the bulk density of the prepared coconut shell activated carbon was high and similar to those reported in literature. Bulk densities of commercial carbons in the range of 0.47 to 0.54 g/cm3 have been reported by previous researcher (Rao *et al*., 2003). Higher bulk density also imparts more mechanical strength on activated carbon (Balakrishnan *et al*., 2007).

Exhaust Quality

The gases detected by the gas analyzer included Hydrocarbon (HC), Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen Oxide (NO_x) and Oxygen (O_2).

Removal of Gaseous Pollutants from the Exhaust using Coconut shell Activated Carbon as adsorbent

The concentrations of some of the constituents of the exhaust fumes (HC, CO, CO_2, O_2, NO_x) with and without the adsorbent (activated carbon) are presented in the Table 2.

able 2: The Gas Effluent Quality after Adsorption

Emitted pollutants	Control (without adsorbent)	Activated Carbon (g)					Charcoal (g)				
		200	400	600	800	1000	200	400	600	800	1000
HC (ppm)	817	706	679	648	640	634	793	741	726	718	692
NO_x(ppm)	98	69	60	56	51	49	85	81	79	75	71
CO (%)	0.59	0.47	0.44	0.41	0.36	0.35	0.53	0.51	0.49	0.44	0.42
CO_2 (%)	0.61	0.53	0.49	0.43	0.39	0.35	0.60	0.56	0.53	0.48	0.45
O_2 (%)	0.45	0.42	0.38	0.36	0.35	0.34	0.44	0.41	0.39	0.36	0.35

The results obtained in Table 2 shows that with increase in the quantity of adsorbents (200g to 1000g), the pollutant concentration decreased gradually and after, some values (state value) became closer. Though, all the pollutants were not totally removed.

Table 3: Percentage Removal of the Gas Effluent after Adsorption

Emitted pollutants	Control (without adsorbent)	Activated Carbon (g)			101		Charcoal (g)				
		200	400	600	800	1000	200	400	600	800	1000
HC (ppm)	817	13.6	16.9	20.7	21.7	22.4	2.9	9.3	11.1	12.1	15.3
NO_x(ppm)	98	29.6	38.8	42.9	47.9	50.0	13.3	17.3	19.4	23.5	27.6
CO (%)	0.59	20.3	25.4	30.5	38.9	40.7	10.2	13.6	16.9	25.4	28.8
CO_2 (%)	0.61	13.1	19.7	29.5	36.1	42.6	1.6	8.2	13.1	21.3	26.2

It is evident from the results obtained in Table 3 that CO removal efficiency was about 40.7% and 28.8% with 1000 g of activated carbon and charcoal as adsorbents respectively. This shows that activated carbon performed better than charcoal made from coconut shell in the purification of exhaust from a gasoline powered generator and this could be due to the fact that activated carbon has higher surface area. From industrial point of view, it is very important to know the quantity of adsorbents needed for the purification of gasoline generator exhaust fumes.

Effect of Using Coconut shell charcoal as pre-filter and Activated Carbon as filter on the Removal of Gaseous Pollutants from the Exhaust

The effect of using coconut shell charcoal as pre-filter and activated carbon as filter on the removal of gaseous pollutants was investigated to determine whether or not the coconut shell charcoal can make up for more removal of pollutants. Figures 1 - 4 show the gas effluent quality after passing the exhaust through a combination of activated carbon and coconut shell charcoal in ratios 1:0.2, 1:0.4, 1:0.6, 1:0.8 and 1:1.

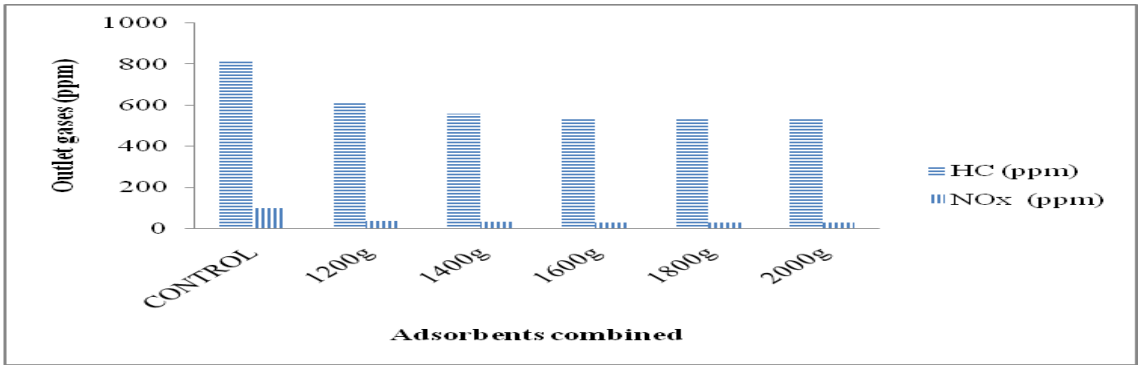


Fig 1: Gas effluent quality after passing through a combination of coconut shell activated carbon and charcoal

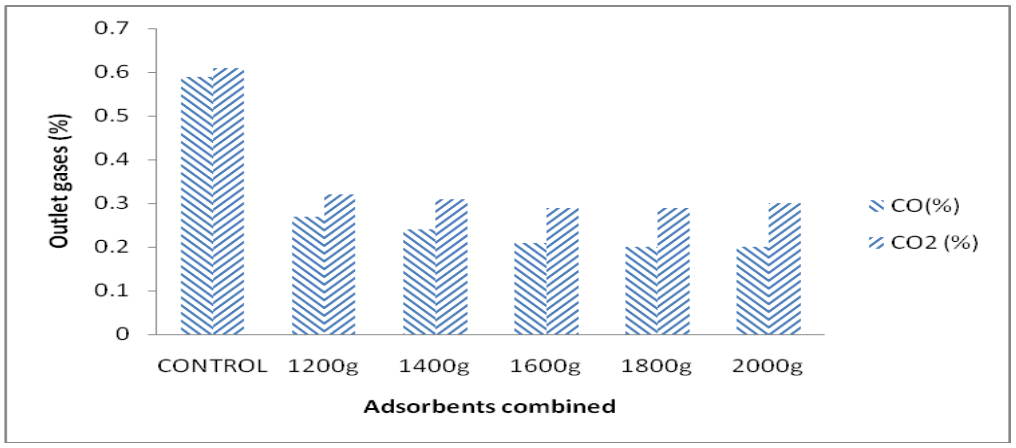


Fig 2: Gas effluent quality after passing through a combination of coconut shell activated carbon and charcoal

In Figures 1 and 2, it was observed that with charcoal as pre-filter and activated carbon as filter, the pollutants concentration decreased rapidly initially(state some of the values) and then gradually. It was also indicated that with increase in adsorbents quantity, pollutants concentration decreased until there were no significant observable differences between the values.

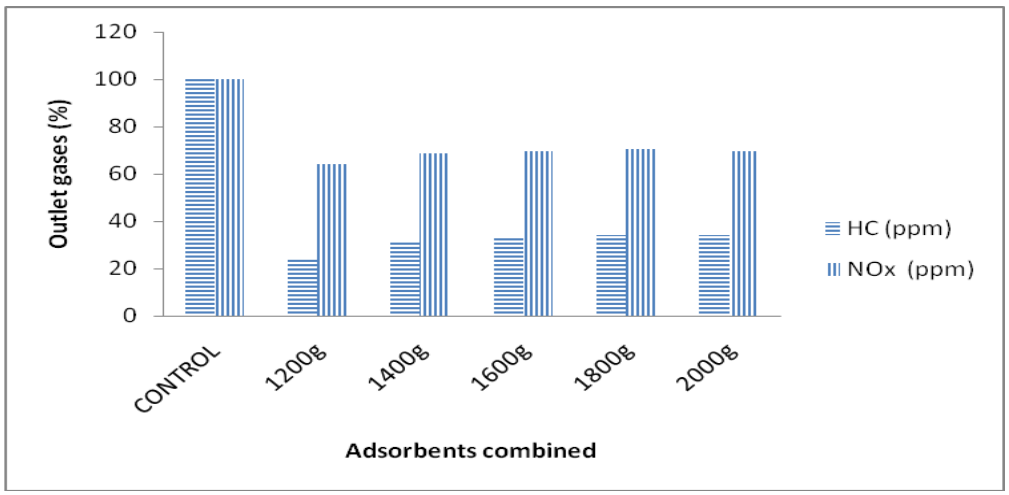


Fig 3: Percentages of the gas effluent removed after passing through a combination of coconut shell activated carbon and charcoal

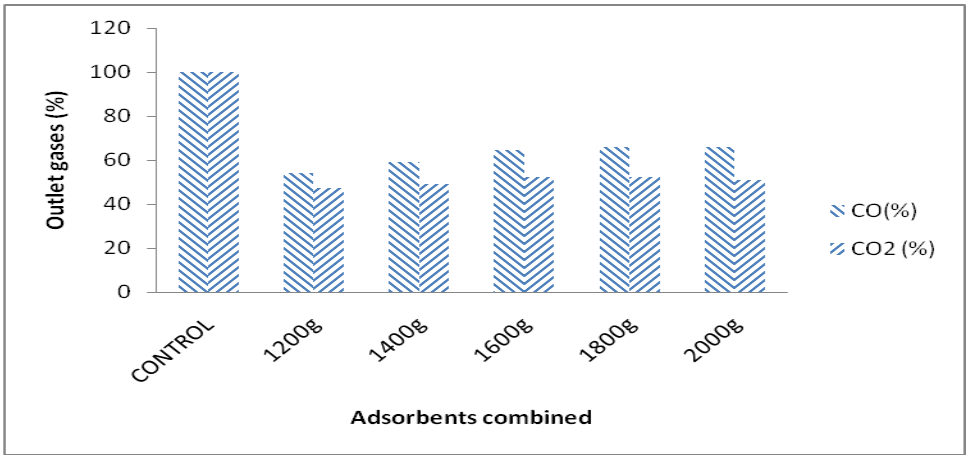


Fig 4: Percentages of the gas effluent removed after passing through a combination ofcoconut shell activated carbon and charcoal

In Figures 3 and 4, increase in the quantity of charcoal as pre-filter and activated carbon as filter, resulted to gradual increase in the percentage of pollutants removed until there were no significant observable differences between the values. This resulted to HC, NO_x, CO and CO_2 having maximum percentage removal of 34.3%, 70.4%, 66.1% and 52.5% respectively at a combination of 1000 g of activated

carbon and 800 g of charcoal as filter and pre-filter respectively.

Adsorption Studies of Coconut Shell Charcoal and Activated Carbon

The initial concentrations of HC, NO_x, CO and CO_2 after running the gasoline generator for 60 min without adsorbents were 783 ppm, 77 ppm, 0.52% and 0.55%, respectively. These served as controls.

Breakthrough Curves for adsorption of the pollutants on coconut shell charcoal

The analysis of the breakthrough curves for HC, NO_x, CO and CO_2 were based on the result obtained from the gas analyzer after the gasoline generator exhaust fumes was passed through only 1000 g of coconut shell charcoal for 5, 10, 15, 20 and 25minutes in order to determine the lifespan of the adsorbent column bed (coconut shell charcoal) before reaching the breakthrough point. The results are presented in Figures 5 and 6.

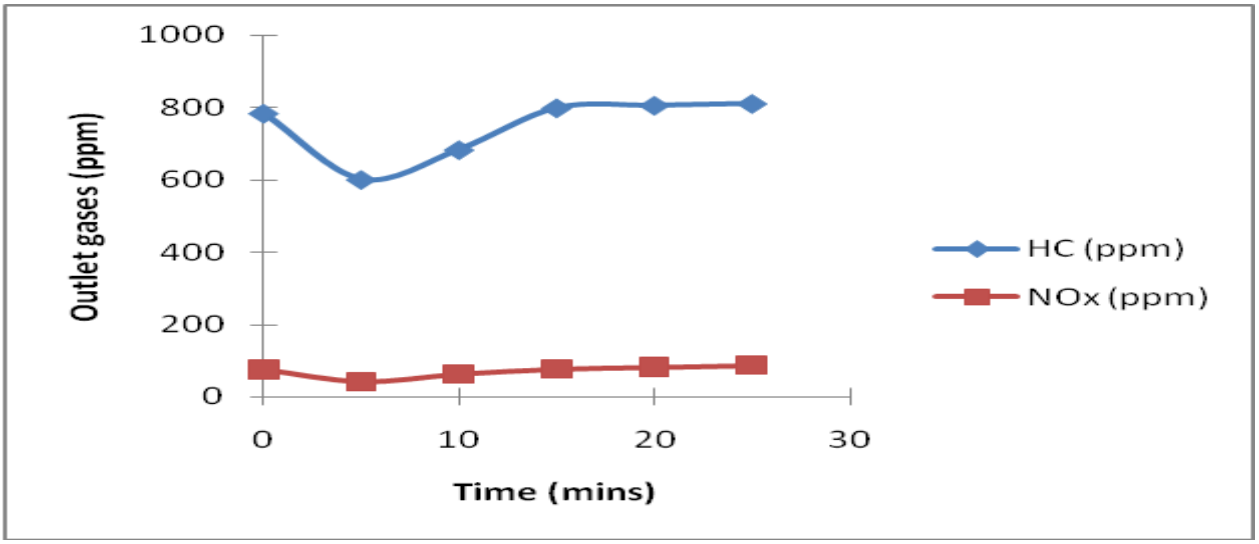


Fig 5: Breakthrough curves for HC and NO_x

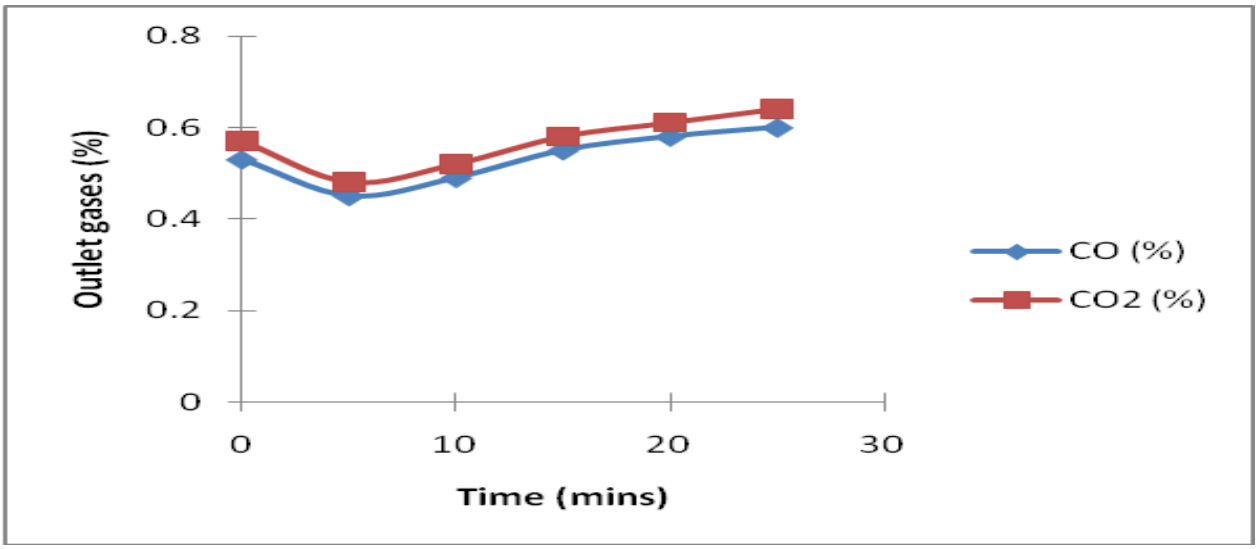


Fig 6: Breakthrough curves for CO and CO_2

The concentration of all the gases decreased for the first 5 min after which they started increasing gradually until the surfaces of the coconut shell charcoal became saturated (or exhausted) at about 15minutes (state some of the value obtained). This implies that the outlet gases exceeded the inlet gases about 15 min of passing the gasoline generator exhaust through coconut shell charcoal.

Breakthrough Curves for adsorption of the pollutants on coconut shell activated carbon

The analysis of the breakthrough curves for HC, NO_x, CO and CO_2 were also based on the result obtained from the gas analyzer after the gasoline generator exhaust fumes was passed through only 1000 g of activated carbon made from coconut shell charcoal for 5, 10, 15, 20 and 25 minutes in order to determine the lifetime of the adsorbent column bed

(coconut shell activated carbon) before the breakthrough point. The results are presented in Figures 7 and 8.

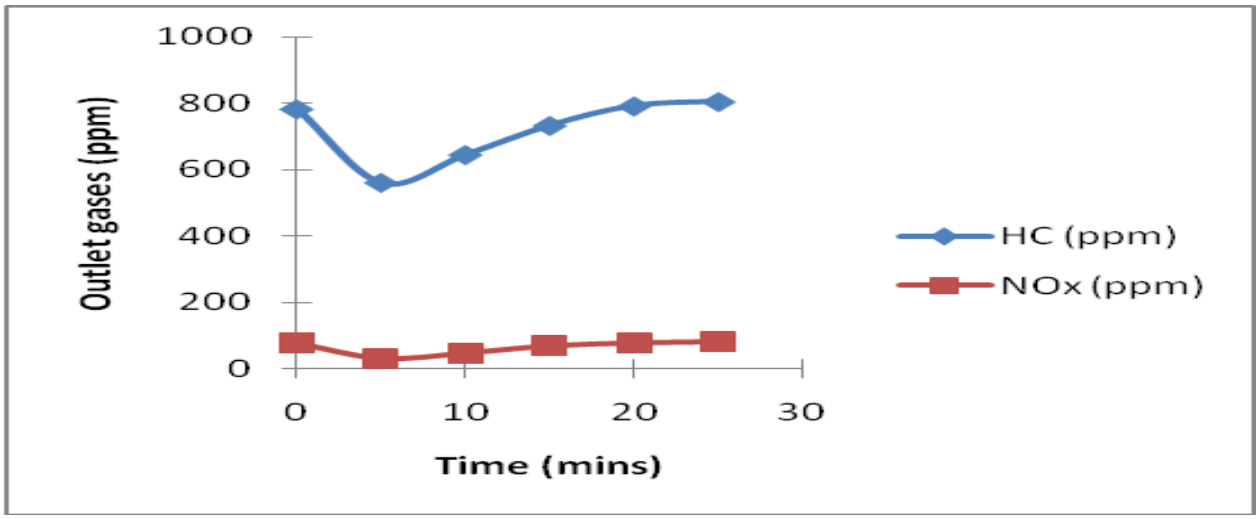


Fig 7: Breakthrough curves for HC and NO_x

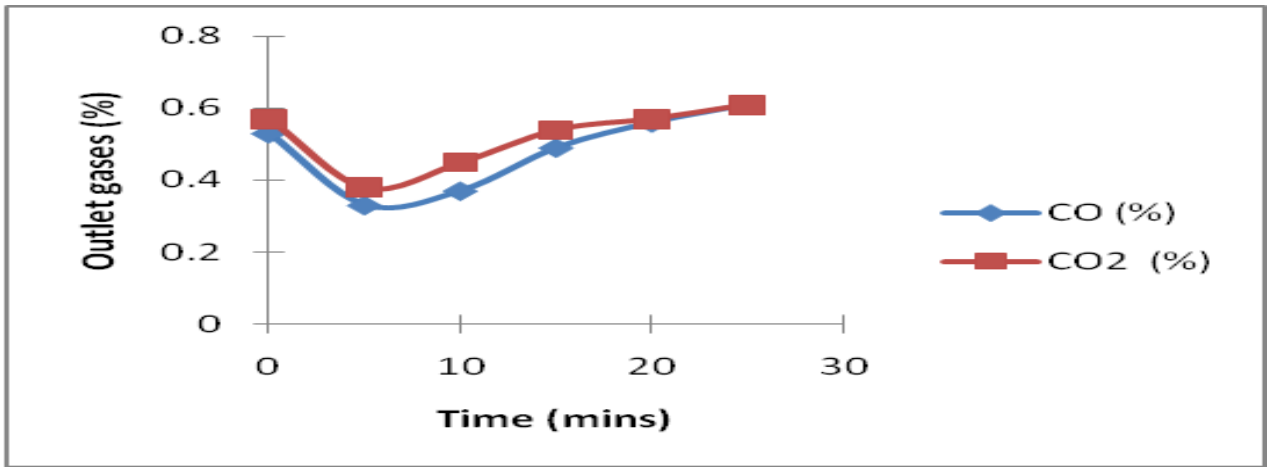


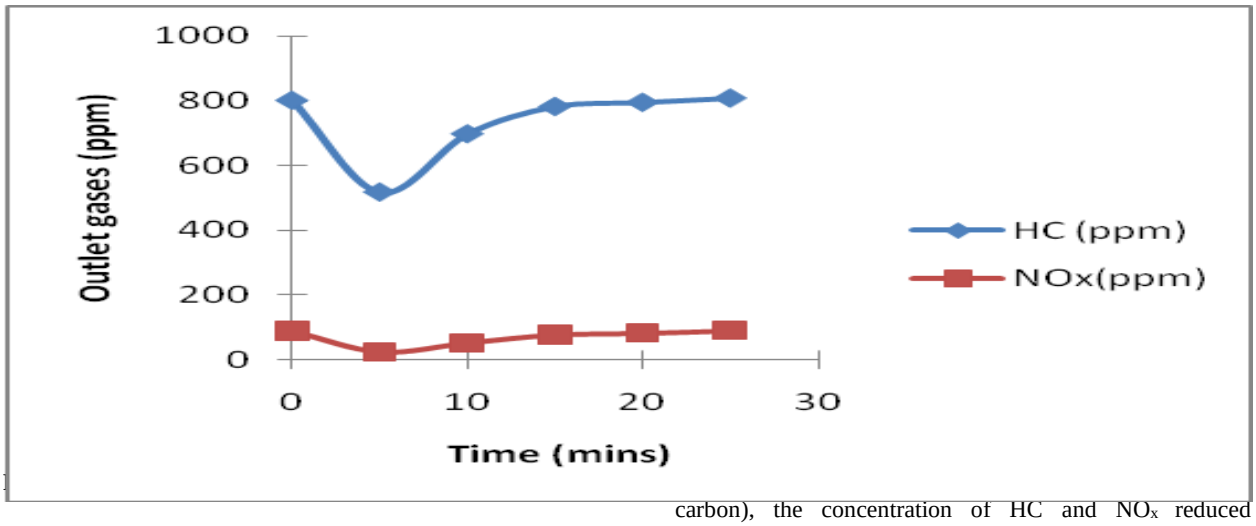
Fig 8: Breakthrough curves for CO and CO_2

The breakthrough curves showed that the concentration of all the gases decreased for the first 10 minutes after which they started increasing gradually until the surfaces of the coconut shell charcoal became saturated (or exhausted) at about 20 min. This implies that the outlet gases exceeded the inlet gases at about 20 minutes of passing the gasoline generator exhaust through coconut shell activated carbon.

Breakthrough Curves for adsorption of the pollutants on charcoal (pre-filter) and activated carbon (filter) made from coconut shells

The initial concentrations of HC, NO_x, CO and CO_2 after running the gasoline generator for 60 min without any adsorbent were 802 ppm, 89 ppm, 0.52% and 0.55%, respectively.

The analysis of the breakthrough curves for HC, NO_x, CO and CO_2 were based on the result obtained from the gas analyzer after the gasoline generator exhaust fume was passed through 800 g of coconut shell charcoal (pre-filter) and then 1000g of activated carbon (filter) for 5, 10, 15, 20 and 25minutes in order to determine the lifetime of the adsorbent column bed (coconut shell charcoal and activated carbon) before the breakthrough point. The results are presented in Figures 9 and 10.



HC and NO_x showed a breakthrough curve with a short adsorption zone in relation to the over-all bed depth (Figure 9). Passing the gasoline generator exhaust fumes through the pre-filter (coconut shell charcoal) and filter (activated carbon), the concentration of HC and NO_x reduced drastically to 517 ppm after 5mins but increased gradually to 809 ppm after 25 mins. The optimum contact time for the removal of these contaminants (HC and NO_x) was determined to be 20mins.

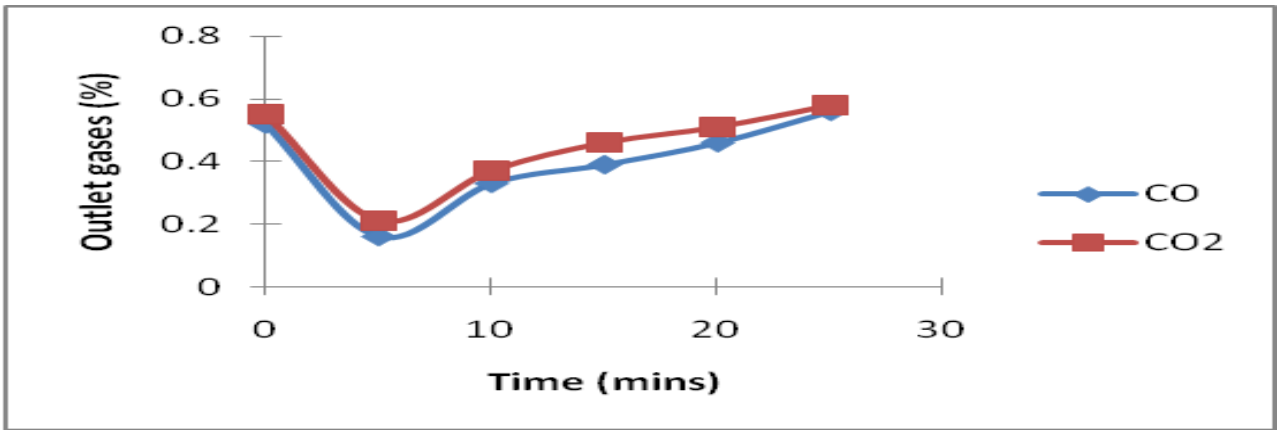


Fig 10: Breakthrough curves for CO and CO_2

CO and CO_2 also showed a breakthrough curve with a short adsorption zone in relation to the over-all bed depth (Fig 10). After passing the gasoline generator exhaust fumes through the pre-filter (coconut shell charcoal) and filter (activated carbon), the concentration of CO and CO_2 reduced to 0.16% and 0.21% after 5mins but increased gradually to 0.56% and 0.58% after 25 mins, respectively. The optimum contact time for the removal of these contaminants (CO and CO_2) was determined to be 20mins.

CONCLUSION

The pollutants emitted from the gasoline powered generator were HC, NOx, CO_2 and CO.

The results obtained in this study showed that granular activated carbon produced from coconut shells can be used for the reduction of pollutants present in gasoline generator exhaust fumes.

This study also shows that coconut shell charcoal can be used as pre-filter to activated carbon in the purification of gasoline generator exhaust fumes.

Combination of 1000 g of activated carbon (filter) and 800 g of charcoal (pre-filter) produced from coconut shells achieved optimum pollutant removal of 34.1% HC, 70.4% NO_x, 66.1% CO and 52.5% CO_2. The agricultural wastes (coconut shells) have the potential of being used as adsorbents for exhaust purification.

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