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Research Paper

Characterization of gaseous emissions from the combustion of some common charcoal in southwestern Nigeria.

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ABSTRACT:*In the developing countries of the world like Nigeria charcoal is a common source of fuel that is extensively used and this can leads to the emission of various pollutants which are harmful to human health. The aim of this study is to characterize the gaseous emission from the combustion of some common wood charcoal species in southwestern Nigeria using E8500 portable industrial combustion analyzer. The criteria pollutants emissions from this study are CO, HC, NO, and NO_x The results obtained showed that the emission factor were of the range 4.850 – 26.392 g/kg with an arithmetic mean of 17.092± 7.483 g/kg for CO, 8.58$\times 10^{-4}$ – 3.01$\times 10^{-4}$ g/kg with an arithmetic mean of 4.85$\times 10^{-4} \pm 1.631 \times 10^{-4}$ g/kg for HC, 0 – 1.84$\times 10^{-2}$ g/kg with an arithmetic mean of 3.28$\times 10^{-3} \pm 5.948 \times 10^{-3}$ g/kg for NO and 0 – 1.84$\times 10^{-2}$ g/kg with an arithmetic mean of 3.28$\times 10^{-3} \pm 5.948 \times 10^{-3}$ g/kg for NO_x. The maximum impact on CO was from Vitellariaparadoxum, the maximum impact on HC, NO and NO_x was from Albiziazygia. The minimum impact on CO was from Milletiathoninngii, the minimum impact on HC was from Miliciaexcelsa and the minimum impact on NO, NO_x was from Funtumiaelastica*

KEYWORDS:*Charcoal, Emission, Analyzer, Pollution, Combustion*

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I. INTRODUCTION

Sustainable development is the current national development, policies and strategies of many nations of the world. In New York, the General Assembly of United Nations presented a set of global Sustainable Development Goals (SDGs) which included 17 goals and 169 targets by the Open Working Group. Also in March 2015, a set of 330 indicators was presented (Lu, et al., 2015). In solving the problem of climate change, renewable energy, water, health and food provision demands a global monitoring and modelling of several factors which are environmentally, economically and socially oriented (Hák, et al., 2016; Owusu, et al., 2016). In the world today, the need for energy is increasing with increasing population and has led to the constant use of fuel from fossil fuel (Gas, Oil and Coal) which now a problem (causing several challenges such as: reduction in fossil fuel reserves, greenhouse gas emissions and other environmental hazards, geopolitical and military conflicts, and the endless fluctuation in fuel price. These challenges will result in unsustainable conditions which will finally lead to possibly permanent threat to human and ecosystem (UNFCC, 2015).

In recent times, renewable energy is a better option than fossil fuel (Krecl at al., 2017). Charcoal is a significant source of fuel especially for cooking (Bonjour, 2013). Despite the advancement in fuel consumption patterns, the use of charcoal especially for cooking and heating cannot be overemphasized in the developing world. Charcoal barbecue is widely used by in restaurants, road side and household (Johnson, 2009; Adam, 2009). In 2014, the production of charcoal is about 61% of global production (Vicente, 2018).

Charcoal is produced through the slow pyrolysis of organic substance (wood) in limited or absence of air. Numerous researches concentrated on the emissions from the production of charcoal (Pennise, 2001; Kammen, 2005, 2005; Adam, 2009; Akagi, 2011; Sparrevik, 2014).Apart from the production process, the combustion of charcoal is a source of pollution. This results in the emission of different pollutants (Vicente, 2018). There are two factors that determines the pollutant emission from the burning of charcoal namely: the process of producing charcoal and the nature of raw materials (Olsson, 2003; Kabir, 2010; Rahman, 2012; Huang, 2016).

II. MATERIALS AND METHODS

Nine charcoal species were collected from southwestern Nigeria. The samples were identified and prepared for analysis. The charcoal species includes: *Anogeissusleiocarpa* (Ayin), *Vitellariaparadoxum*(Emi), *Burkea Africana* (Asapa), *Albiziazygia* (Ayunre), *Heveabrasiliensis*(Rubber), *Miliciaexcelsa* (Iroko), *Terminaliaavicennioides* (Idi), *Funtumiaelastica* (Ire), *Milletiathonningii* (Ito).

2.1 Study Area

The study area is south-western Nigeria and these includes of Lagos, Ogun, Oyo, Osun, Ondo and Ekitistates. It is also called the south west geographical zone of Nigeria and the map is shown in figure 3.1. The longitude of the area lies $2°31^1$ and $6°00^1$ East and Latitude $6°21^1$ and $8° 37^1$N (Agboola, 1979) with about 77,818 km^2 land area and the population is about 32.5 million in 2006 (NPC, 2006). South western, Nigeria is bounded in the North by Kogi and Kwara states, in the South by the Gulf of Guinea, in the East by Delta and Edo states and in the West by Benin Republic. The study area had a forest cover of 842,499 ha and 85 constituted forest reserves.

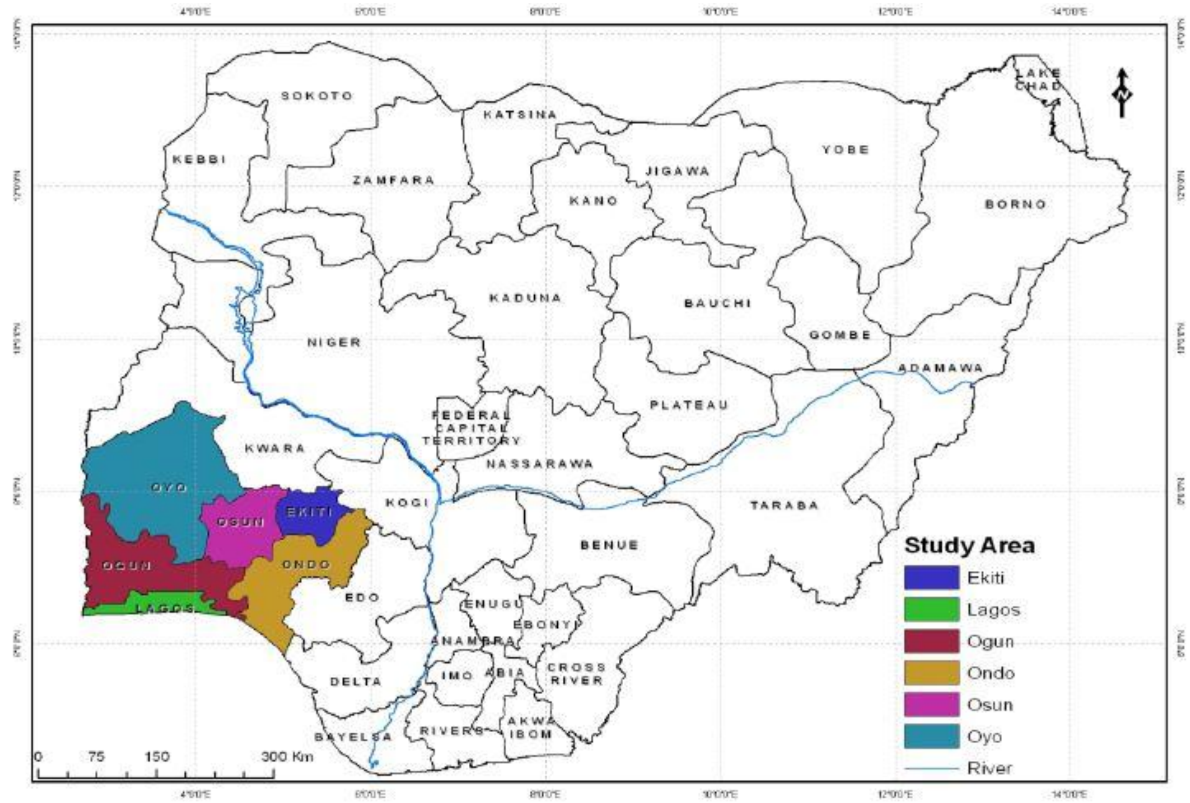

Figure 3.1 Map showing the study area (Faleyimu, 2010)

2.2 Experimental Procedure

About 50 g of each of the identified charcoal in the Southwestern, Nigeria used as a source of energy was subjected to open burning in the Environmental Engineering Research Laboratory of the Department. During the burning, air emissions from the charcoal was analyzed for criteria air pollutants including Carbon monoxide (CO), Oxygen (O_2), Hydrocarbons (HC), Carbon monoxide (CO), Carbon dioxide (CO_2), Nitric oxide (NO), NO_2, and NO_x), Hydrogen Sulphide (H_2S) using the E-instrument E8500 combustion analyzer. The charcoal was allowed to burn out completely and the time taken for the charcoal to burn out completely into ashes was observed and recorded. To determine the emission factor of the criteria air pollutants from the open burning of the identified charcoal, parameter including concentration of air pollutants, flow rate of the measured pollutants, mass of the charcoal burnt and time taken for complete burn out of the charcoal was used. Equations (2.1) and (2.2) was used in estimating the emission factor of the air pollutants in the emissions.

$n = C_p * F * t$ (2.1)

$EF = \frac{n}{M}$ (2.2)

n = mass of pollutant released in mg

C_p = concentration of pollutant measured in $\frac{mg}{m^3}$

F = flow rate in $\frac{m^3}{s}$
t = time taken in seconds for complete burning of the charcoal.
M = mass of the charcoal burnt in kg.
EF = emission factor of the pollutant in $\frac{mg}{kg}$

III. RESULTS AND DISCUSSION

During this study, the gaseous emission characterized from the identified charcoals were Hydrocarbons (HC), Oxides of Nitrogen (NO_x), Nitric oxide (NO), Carbon monoxide (CO) and Sulphur dioxide (SO_2) which are of great interest to human and the environmental specialist, as they are coming up with different ways of minimizing the effect of these pollutants.

According to the identified charcoals, the CO measured were 431.409 – 640.534 mg/m^3 with a mean value of 525.424 ± 106.147 mg/m^3 HC were 0.00533 – 0.0210 mg/m^3 with a mean value of 0.01066 ± 0.00896 mg/m^3, NO, NO_x and SO_2 were not present for *Anogeissusleiocarpa*. For *Vitellariaparadoxum*, CO measured were of the range 525.922 – 1290.373 mg/m^3 with a mean of 919.674 ± 382.274 mg/m^3, HC were 0.00863 – 0.0177 mg/m^3 with a mean of 0.0137 ± 0.00464 mg/m^3, NO were 0.00 – 0.409 mg/m^3 with a mean of 0.136 ± 0.236 mg/m^3, NO_x were 0.00 – 0.409 mg/m^3 with a mean of 0.136 ± 0.236 mg/m^3, SO_2 were not present. CO measured were of the range 131.138 – 522.936 mg/m^3 with a mean of 277.776 ± 213.674 mg/m^3, HC were 0.0000809 – 0.0188 mg/m^3 with a mean of 0.00986 ± 0.00939 for *Burkea Africana*. For *Albiziazygia*, the pollutants emitted were of the range 398.744– 724.632 mg/m^3 with a mean of 537.100 ± 168.417 mg/m^3 for CO, 0.0152 – 0.0293 mg/m^3 with a mean of 0.0201 ± 0.00797 mg/m^3 for HC, 0.0744 – 1.061 mg/m^3 with a mean of 0.5000 ± 0.507 mg/m^3. For *Miliciaexcelsa*, CO measured were of range 170.295 – 277.793 mg/m^{3}with a mean of 213.968 ± 56.511 mg/m^3, HC were 0.00428 – 0.0210 mg/m^3 with a mean of 0.0103 ± 0.0093 mg/m^3.

For *Terminaliaavicennioides*, CO measured were of range 212.069 – 765.163 mg/m^3 with a mean of 398.464 ± 317.585 mg/m^3, HC were 0.00655 – 0.0136 mg/m^3 with a mean of 0.0102 ± 0.0353 mg/m^3, NO were 0.00 – 0.360 mg/m^3 with a mean of 0.120 ± 0.208 mg/m^3, NO_x were 0.00 – 0.360 mg/m^3 with a mean of 0.120 ± 0.208 mg/m^3. For *Funtumiaelastica*, the pollutants emitted were of the range 253.840 – 628.922 mg/m^3 with a mean of 400.819 ± 200.269 mg/m^3 for CO, 0.0126 – 0.01704 mg/m^3 with a mean of 0.0144 ± 0.00262 mg/m^3 for HC, 0.00 – 0.149 mg/m^3 with a mean of 0.07446 ± 0.0745 mg/m^3. For *Milletiathonningii*, CO measured were of range 135.910 – 154.310 mg/m^3 with a mean of 143.513 ± 9.607 mg/m^3, HC were 0.00347 – 0.0165 mg/m^3 with a mean of 0.0098 ± 0.00652 mg/m^3. For *Heveabrasiliensis*, the pollutants emitted were of range 301.572 – 1094.821 mg/m^3 with a mean of 636.403 ± 410.812 mg/m^3, HC were 0.00953 – 0.0197 mg/m^3 with a mean of 0.0134 ± 0.0055 (Table 1).

Vitellariaparadoxum has the maximum average CO emission while *Milletiathonningii* has the minimum average CO emission. *Albiziazygia* has the maximum average HC emission while *Terminaliaavicennioides* has the minimum average HC emission. *Albiziazygia* has the maximum average NO and NO_x emission while *Funtumiaelastica* has the minimum average NO and NO_x emission. Both NO and NO_x emission are not found in *Anogeissusleiocarpa*, *Burkea Africana*, *Milletiathonningii*and *Heveabrasiliensis*. SO_2 is not emitted in any of the charcoals.

Table 1 Descriptive statistics of the emissions from selected charcoal

Gaseous Emission	Mean	Standard deviation	Minimum	Maximum	Range
CO	450.349	237.959	143.513	919.674	776.161
HC	0.01249	0.00338	0.0098	0.02010	0.01030
N	0.20725	0.19665	0.0745	0.50000	0.50000
NO_X	0.20725	0.19665	0.0745	0.50000	0.50000
SO_2	0.00000	0.00000	0.0000	0.00000	0.00000
H_2S	0.00000	0.00000	0.0000	0.00000	0.00000

The burnout time for these charcoals were in the range 3360 – 5180 seconds with a mean of 4380 ± 923.69 seconds for *Anogeissusleiocarpa*, for *Afzeliabipindensis*, the time were in the range 7200 – 7500 seconds with a mean of 7350 ± 150.00 seconds

For *Vitellariaparadoxum*, the time were in the range of 2400 – 3540 with a mean of 3040 ± 582.72 seconds, 5430 – 5940 seconds with a mean of 5720 ± 330.45 for *Burkeaafricana*, 3900 – 5100 seconds with a mean of 4520 ± 600.99 seconds for *Albiziazygia*, for *Miliciaexcelsa*, the time were in the range of 2700 – 3420 seconds with a mean of 3100 ± 366.61 seconds, 4380 – 6840 seconds with a mean of 5220 ± 1403.28 seconds for *Terminaliaavicennioides*, 3900 – 4080 seconds with a mean of 3980 ± 91.65 seconds for *Funtumiaelastica*, 3240 – 3780 seconds with a mean of 3580 ± 295.97 seconds for *Milletiathonningii*, 3420 – 3780 seconds with a mean of 3660 ± 207.85 seconds for *Heveabrasiliensis. Vitellariaparadoxum* has the minimum average burnout time while *Burkeaafricana* has the maximum average burnout time.

The calculated emission factors which is the mass of emitted pollutants per unit time from the open burning of the identified common Charcoal in southwestern Nigeria were presented in Table 2.

For *Anogeissusleiocarpa*, 21.725 g/kg is the emission factor for CO, 4.408×10^{-4} g/kg is the emission factor for HC. For*Afzeliabipindensis*, emission factors of these pollutants were 6.748 g/kg for CO, 4.482×10^{-4}g/kg for HC. For *Vitellariaparadoxum*, emission factors of these pollutants were 26.392 g/kg for CO, 3.932×10^{-4} g/kg for HC, 3.903×10^{-3} g/kg for NO and 3.903×10^{-3} g/kg for NO_x. For *Burkeaafricana*, emission factors for these pollutants were 14.999 g/kg for CO, 5.324×10^{-4}g/kg for HC. For *Albiziazygia*, the emission factors of these pollutants were 22.917 g/kg, 8.576×10^{-4} g/kg, 1.835×10^{-2}g/kg and 1.835×10^{-2} g/kg for CO, HC, NO and NO_x respectively. For *Terminaliaavicennioides*, the emission factors were 19.635 g/kg for CO, 5.026×10^{-4} g/kg for HC, 4.509×10^{-3} g/kg for NO and 4.509×10^{-3} g/kg for NO_x. The emission factors of the pollutants from *Miliciaexcelsa* were 6.262 g/kg for CO, 3.014×10^{-4} g/kg for HC. For *Funtumiaelastica*, emission factors of these pollutants were 15.059 g/kg for CO, 5.410×10^{-4} g/kg for HC, 2.798×10^{-3} g/kg for NO and 2.798×10^{-3} g/kg for NO_x. For *Milletiathonningii*, emission factors were 4.850 g/kg and 3.312×10^{-4} g/kg for CO and HC respectively. The emission factors from *Heveabrasiliensis*were 21.988 g/kg for CO and 4.630×10^{-4} g/kg for HC. *Vitellariaparadoxum*has the maximum emission factor for CO, *Albiziazygia*has the maximum emission factor for HC, NO and NO_x While *Milletiathonningii* has the minimum emission factor for CO, *Miliciaexcelsa*has minimum emission factor for HC and *Funtumiaelastica*has the minimum emission factor for NO and NO_x. The descriptive analysis of the emission factor are presented in Table 3.

Table 2 Emission factor of gaseous emission concentrations from Charcoal species.

S/N	Charcoal Samples	Emission Factor (g/kg)					
		CO	HC	NO	NO_x	SO_2	H_2S
1.	*Anogeissusleiocarpa*	21.725	0.000441	0.0000	0.0000	0.0000	0.0000
2.	*Vitellariaparadoxum*	26.392	0.000393	0.0039	0.0039	0.0000	0.0000
3.	*Burkeaafricana*	14.999	0.000532	0.0000	0.0000	0.0000	0.0000
4.	*Albiziazygia*	22.917	0.000858	0.0184	0.0184	0.0000	0.0000
5.	*Miliciaexcelsa*	6.262	0.000301	0.0000	0.0000	0.0000	0.0000
6.	*Terminaliaavicenn.*	19.635	0.000503	0.0045	0.0045	0.0000	0.0000
7.	*Funtumiaelastica*	15.059	0.000541	0.0036	0.0036	0.0000	0.0000
8.	*Milletiathonningii*	4.850	0.000331	0.0000	0.0000	0.0000	0.0000
9.	*Heveabrasilensis*	21.988	0.000463	0.0000	0.0000	0.0000	0.0000

Table 3 Descriptive statistics of the emission factors from selected charcoal

Gaseous Emission	Mean	Standard deviation	Minimum	Maximum	Range
CO	17.09180	7.48320	4.85000	26.39200	21.54200
HC	0.00049	0.00016	0.00030	0.00086	0.00056
NO	0.00493	0.00685	0.00000	0.01835	0.01835
NO_X	0.00493	0.00685	0.00000	0.01835	0.01835
SO_2	0.00000	0.00000	0.00000	0.00000	0.00000
H_2S	0.00000	0.00000	0.00000	0.00000	0.00000

The calculated emission rate of the gaseous pollutants of the identified charcoal in southwestern Nigeria are discussed below. For *Anogeissusleiocarpa*, 2.480×10^{-4} g/s the emission rate for CO, 5.032×10^{-9} g/s is the emission rate for HC. For *Vitellariaparadoxum*, emission rates of these pollutants were 4.341×10^{-4} g/s for CO, 6.467×10^{-9} g/s for HC, 6.419×10^{-8} g/s for NO and 6.419×10^{-8} g/s for NO_x. For *Burkeaafricana*, emission rates for these pollutants were 1.311×10^{-4} g/s for CO, 4.654×10^{-9}g/s for HC. For *Albiziazygia*, the emission rates of these pollutants were 2.535×10^{-4} g/s, 9.487×10^{-9} g/s, 2.030×10^{-7} g/s, and 2.030×10^{-7} g/s for CO, HC, NO and NO_x respectively. For *Terminaliaavicennioides,* the emission rates were 1.881×10^{-4} g/s for CO, 4.814×10^{-9} g/s for HC, 4.319×10^{-8} g/s for NO and 4.319×10^{-8} g/s for NO_x. The emission rates of the pollutants from *Miliciaexcelsa* were 1.010×10^{-4} g/s for CO, 4.861×10^{-9} g/s for HC. For *Funtumiaelastica*, emission rates of these pollutants were 1.892×10^{-4} g/s for CO, 6.796×10^{-9} g/s for HC, 3.515×10^{-8} g/s for NO and 3.515×10^{-8} g/s for NO_x. For *Milletiathonningii*, emission rates were 6.774×10^{-5}g/s and 4.626×10^{-9} g/s for CO and HC respectively. The emission rates from *Heveabrasiliensis*were 3.004×10^{-4} g/s for CO and 6.325×10^{-9} g/s for HC. *Vitellariaparadoxum*has the maximum emission rate for CO, *Albiziazygia*has the maximum emission rate for HC, NO and NO_x While *Milletiathonningii* has the minimum emission rate for CO, *Burkeaafricana* has minimum emission rate for HC and *Funtumiaelastica* has the minimum emission rate for NO and NO_x.

Ultimate analysis is good for predicting the elements that cause increase in harmful emission, one of the major problems of the use of biomass (Biswas*et al.*, 2014). The ER of CO shows a negative correlations with volatile matter (r = -0.69), low positive correlation with moisture content (r = -0.19), hydrogen content (r = 0.036), moderately positive correlation with fixed carbon (r = 0.51) and carbon content (r = 0.66). This indicates that the higher the ratio of carbon content and fixed carbon, the higher the concentration of CO released and the higher the ratio of volatile matter and moisture content, the lower the concentration of CO released as shown in figure 1 to 5. The ER of HC shows a negative correlations with volatile matter (r = -0.64), low positive correlation with moisture content (r = -0.24), hydrogen content (r = -0.18), moderately positive correlation with fixed carbon (r = 0.62) and carbon content (r = 0.77). This indicates that the higher the ratio of carbon content and fixed carbon, the higher the concentration of HC released and the higher the ratio of volatile matter, hydrogen content and moisture content, the lower the concentration of CO released as shown in figure 6 to 10.

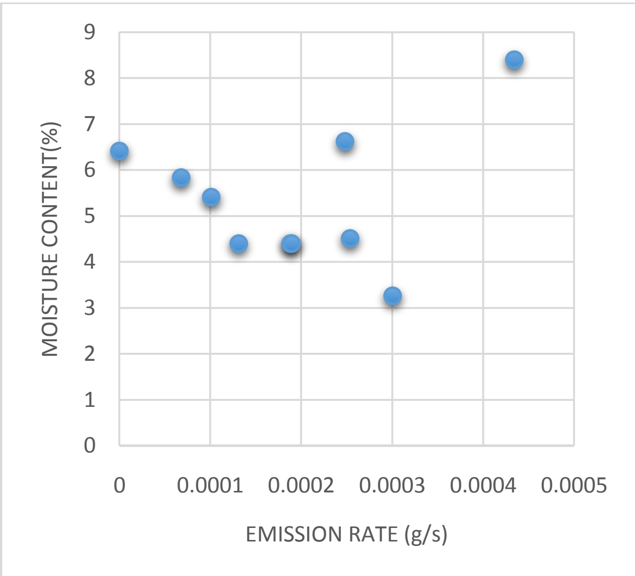

Figure 1 Correlation between Emission rate of CO and moisture content

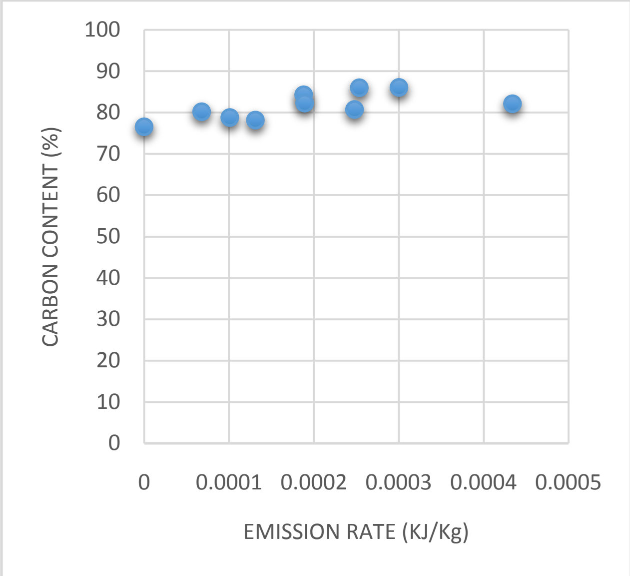

Figure 2 Correlation between Emission rate of CO and carbon content

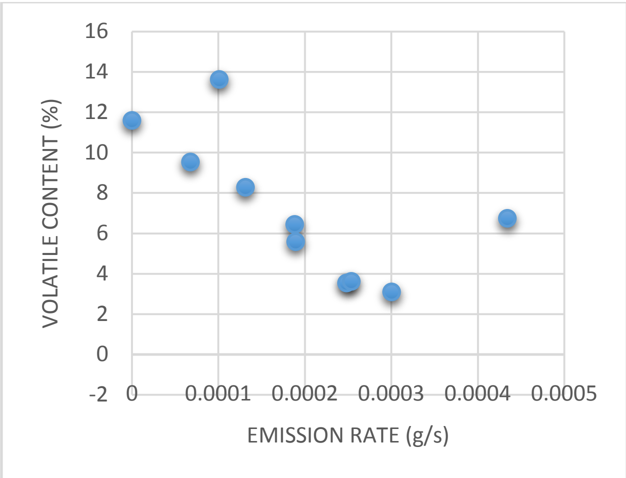

Figure 3 Correlation between Emission rate of CO and volatile matter

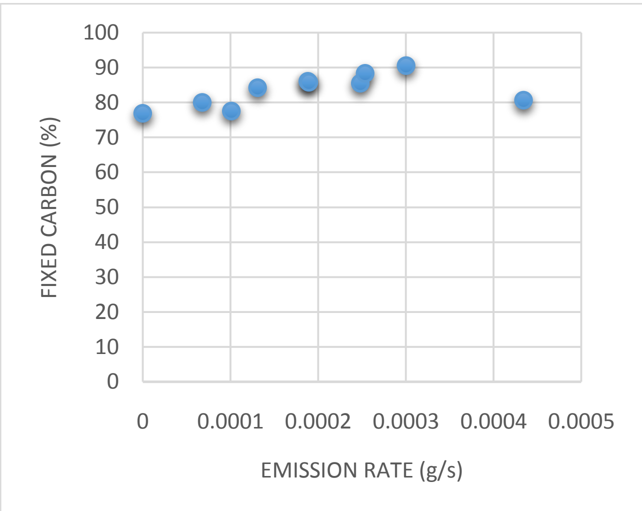

Figure 4 Correlation between Emission rate of CO and fixed carbon

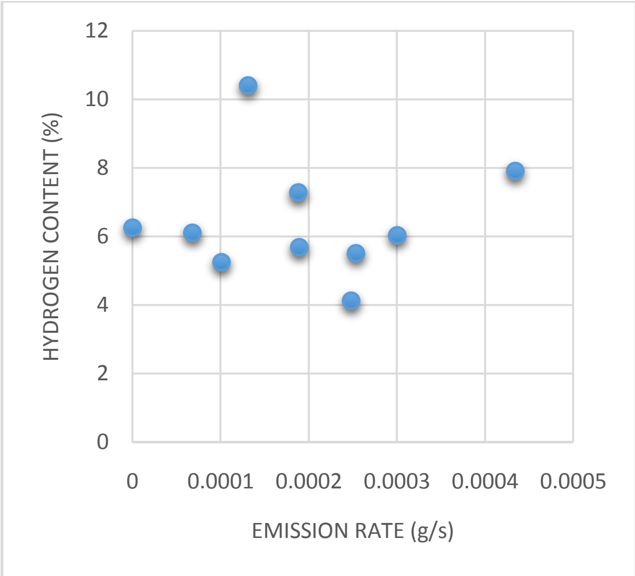

Figure 5 Correlation between Emission rate of CO and hydrogen content

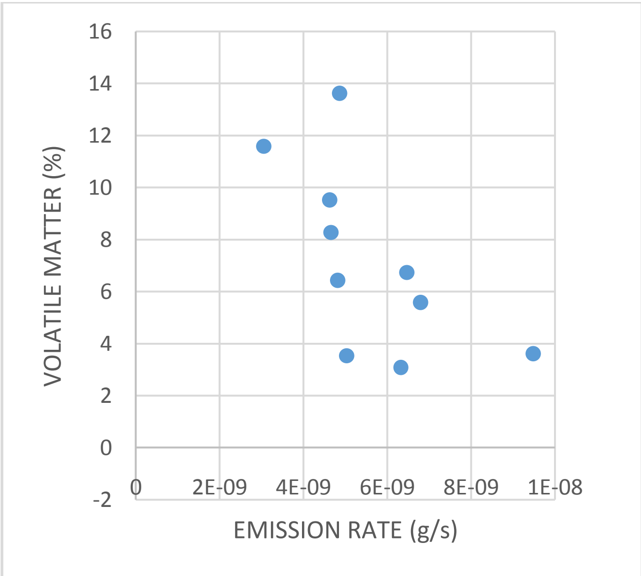

Figure 7 Correlation between Emission rate of HC and volatile matter

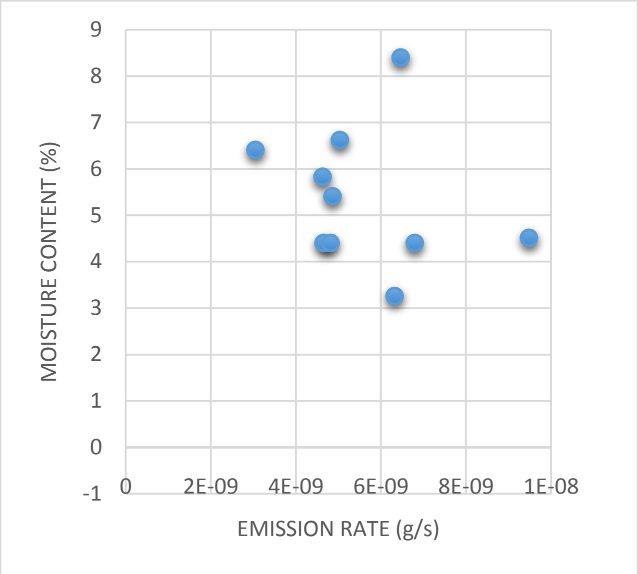

Figure 8 Correlation between Emission rate of HC and moisture content

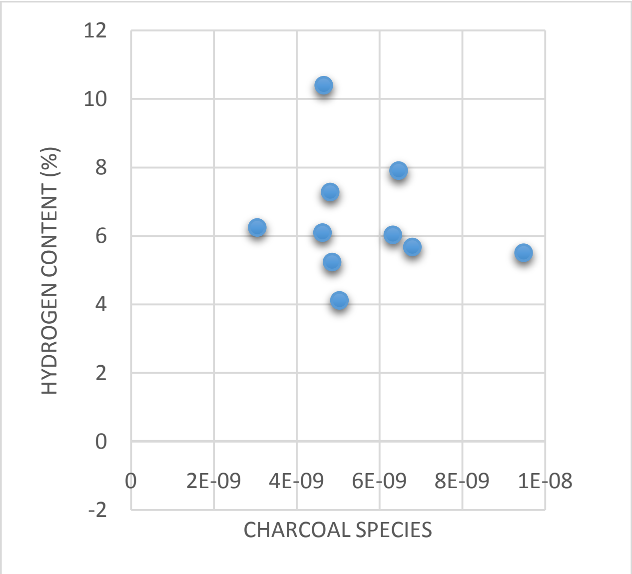

Figure 6 Correlation between Emission rate of HC and hydrogen content

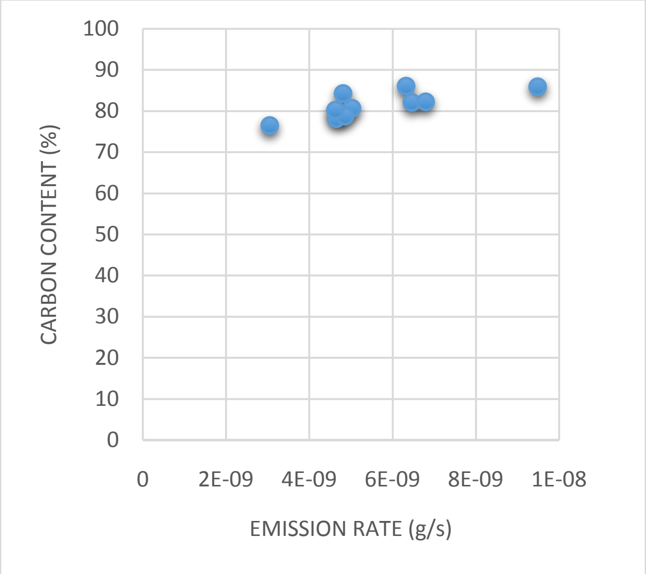

Figure 9 Correlation between Emission rate of HC and carbon content

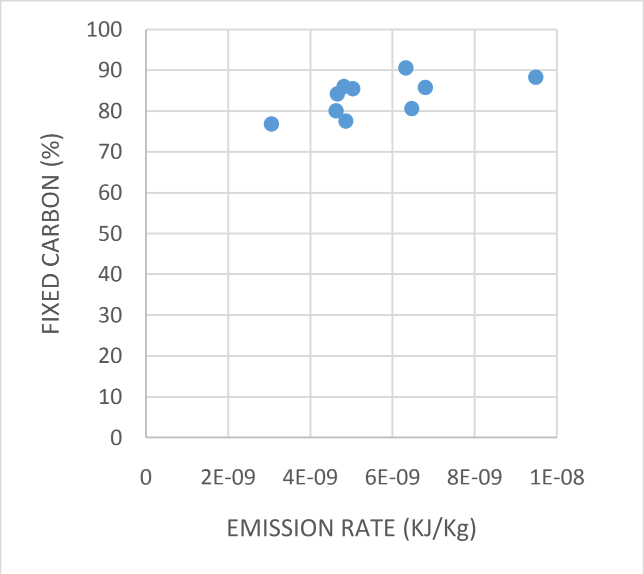

Figure 10 Correlation between Emission rate of HC and fixed carbon conte

IV. CONCLUSION

Emissions of Carbon monoxide, Hydrocarbons, Oxides of Nitrogen, Sulphur dioxide and Hydrogen Sulphide from the burning of charcoal were obtained. The emission factor and the emission rate were estimated. The source emission concentrations of CO from the charcoal when compared with FMEnv (1991) breached the permissible limit for stationary source. For HC, NO and NO_x the emissions were below the recommended limit for stationary source. SO_2 were not dected. The maximum impact on CO was from *Vitellariaparadoxum*, the maximum impact on HC, NO and NO_x was from *Albiziazygia*. The minimum impact on CO was from *Milletiathoninngii*, the minimum impact on HC was from *Miliciaexcelsa* and the minimum impact on NO, NO_x was from *Funtumiaelastica*. This indicates that CO is the most concerning gaseous pollutants.

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