Physical Characterisation of Emission from the Combustion of Household Cooking Fuels in Aiyetoro Community

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The main aim of this research work is to determine the composition and quality of gaseous emission from the cooking fuels. This will aid in providing information that may lead to improved energy consumption while also trying to minimize the fuel users' exposure to gaseous product of incomplete combustion. The data used for the energy consumption study was obtained through a sampling procedure that resulted in a sample size of 76 households used for the study. The emission analysis test was carried out with an emission gas analyser, the quality and composition of emission from fuels such as sheabutter and locust bean fuelwood, sheabutter and locust bean charcoal, kerosene and electricity and it was done under varying conditions as it can be obtained in household cooking conditions. The gaseous emission test reveals hydrocarbon, carbon monoxide, carbon dioxide, oxygen and nitrogen dioxide as the major products of incomplete combustion. In all this cases, except oxygen, the quantity released is up to 500 times what is available in surrounding atmospheric air. Finally, the study suggests formulation and implementation of policies which will encourage the development of technologies that will improve efficiency in the use of traditional fuels while also reducing drastically the emission from such fuels; as these if achieved will reduce the stress and hazard associated with the use of traditional energy

Keyword: combustion, emission characterisation, household cooking fuel,

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1.0   INTRODUCTION.

The pattern of energy consumption in Nigeria's economy is divided into various economic sectors which are: industrial, transport, services and household sectors (ECN, 2007). The household sector accounts for the largest share of energy consumption in the country with about 64%, with energy consuming activities such as: cooking, lightning and use of electrical appliances. Out of the 64% of total energy consumed in the household, cooking accounts for about 70%, lightning uses 3%, hot water boiling takes about 25% and the remaining 2% can be attributed to the use of electrical appliances.(ECN,2012 ; Kulla, Suleiman and Ishaya,2012)

In Nigeria, as it is all over the developing world, meals are cooked mainly with home-made traditional stoves or open fires. These stoves are fired by various forms of renewable non-commercial fuels such as wood, animal residue and charcoal. Solar energy is used in limited cases (Kulla, 2011). It is estimated that as much as 70% of households in developing countries uses fuels such as woods, dung and crop residue for cooking (Rehfuess, 2006).

During the burning of fuels, smoke emitted contains particles and gaseous chemicals such as CO_2, CO, Methane etc.; with this emission more pronounced in traditional biofuels than conventional fuels. Woods and biofuels used for cooking are believed to have contributed about 172Gg of black carbon in 1995 and about 160Gg/year in the decade prior to that (Venkatarama, Habib, Eiguren, Miguel and Friedslander, 2005).

The problems related to the use of biomass as an energy source have been an issue of concern for more than three decades. The traditional stoves commonly used for burning biomass energy have long been found to be highly inefficient and to emit copious quantities of smoke due to incomplete combustion of fuels (WHO, 2010; Grant and Angela, 2010). This inefficiency has also had consequences on the environment, since intense collection of firewood has resulted in deforestation in highly populated areas. In Nigeria, harvesting of fuel-wood

contributes to deforestation at a rate of about 400,000 hectares/annum (Dzioubinski and Chipman, 1999). Aside from the problem of deforestation, the burning of solid fuel also comes with attendant health problems such as death, difficulty in breathing, stinging eye and chronic respiratory disease as a result of indoor air pollution caused by burning of solid fuels. In Nigeria, death from the use of solid fuel stood at a staggering 79,000+ while 3.8% national burden of disease is attributed to the use of solid fuel (GACC, 2011; Regina, 2010). The World Health Organisation (WHO) estimates that more than 1.5million people prematurely die each year due to expose to the smoke and other air pollutants from burning fuels (Refuess, 2006).

All over the developing world, governments have made various attempts to convert households from these fuels to modern fuels or from traditional stoves to more efficient and cleaner burning stoves through reforms of the energy sector or indigenous innovative technology have met with varying degree of success. While it has been effective in some countries it has been dismal or non-existence in some (WHO, 2010; Garba and Atiku, 1997).

In spite of all these negative consequences, there has not been adequate database of emission constituents of various cooking fuels. This study seeks to establish a database of emission gas from the use of cooking fuels peculiar to Aiyetoro community.

This information is expected to help government, Non-governmental organisation and individuals in planning process.

2.0   LITERATURE REVIEW

2.1   Emission Characterisation.

Emission characterisation, which in some instance is also referred to as source characterisation is the measurement of emission from a pollution source and determining the properties and constituents of such emission (Kulla, 2011; Daly and Zannetti, 2007). Emission characterisation provides emission information which can be used by government or organisations to improve their inventories of air pollutants, particulate matter (PM) and other precursor. This information provides critical strategies employed in the management of such pollutants and PM.

2.2   The natural environment and air pollution.

The present-day atmosphere is quite different from the natural atmosphere that existed before the Industrial Revolution, in terms of chemical composition as illustrated in the table below. If the natural atmosphere is considered to be "clean", then this means that clean air cannot be found anywhere in todays' atmosphere (Daly et al, 2007).

Table 1: Chemical composition of the pre-industrial (i.e., before the 18th century), natural global atmosphere as compared to current compositions

Gas	Symbol	% by Volume (current atmosphere)	Ppm (natural atmosphere)	Ppm (current atmosphere)
Nitrogen	N_2	78.1		
Oxygen	O_2	20.9		

Argon	Ar	0.92		
Neon	Ne		18.2	
Helium	He		5.2	
Krypton	Kr		1.14	
Xenon	Xe		0.09	
Carbon dioxide	CO2		280.0	370.0
Methane	CH4		0.750	1.77
Nitrous oxide	N2O		0.0270	0.318
Water vapour	H2O	Variables (0.004 to 4)		

Source: Daly et al (2007).

One could claim that air pollution started when humans began burning fuels. In other words, all man-made (anthropogenic) emissions into the air can be called air pollution, because they alter the chemical composition of the natural atmosphere. The increase in the global concentrations of greenhouse gases; CO_2, CH_4, and N_2O, can be called air pollution using this approach, even though the concentrations have not found to be toxic for humans and the ecosystem.

Similarly, it will be useful to also consider geogenic Emissions (as emissions caused by the non-living world, such as volcanic emissions, sea-salt emissions, and natural fires) and biogenic emissions (such as volatile organic compound (VOC) emissions from forests and CH_4 emissions from swamps) as contributors to air pollution.

Human activity can also influence geogenic and biogenic emissions. For example, human applications of nitrogen fertilizers in agriculture can result in increased biogenic emissions of nitrogen compounds from the soil. Also, humans can affect the biogenic emissions of VOC by cutting down trees or planting trees. Lastly, geogenic emissions of dust from the earth's surface can be altered if the surface is changed by human activity.

So taking all of the above into account, we can define an "Air Pollutant" as any substance emitted into the air from an anthropogenic, biogenic, or geogenic source, that is either not part of the natural atmosphere or is present in higher concentrations than the natural atmosphere, and may cause a short-term or long-term adverse effect (Daly et al,2007).

2.3   Classification of pollutants

Air pollutants can be broadly classified as either a primary or secondary pollutant. Primary pollutants are substances that are directly emitted into the atmosphere from sources. The main primary pollutants known to cause harm in high enough concentrations are the following (Daly et al 2007; Regina 2010):

- Carbon compounds, such as CO, CO_2, CH_4, and VOCs

- Nitrogen compounds, such as NO, N_2O, and NH_3
- Sulphur compounds, such as H_2S and SO_2
- Halogen compounds, such as chlorides, fluorides, and bromides
- Particulate Matter (PM or "aerosols"), either in solid or liquid form, which is usually categorized into these groups based on the aerodynamic diameter of the particles

Secondary pollutants are not directly emitted from sources, but instead form in the atmosphere from primary pollutants (also called "precursors"). The main secondary pollutants known to cause harm in high enough concentrations are the following:

- NO_2 and HNO_3 formed from NO
- Ozone (O_3) formed from photochemical reactions of nitrogen oxides and
-     VOCs
- Sulphuric acid droplets formed from $SO3$, and nitric acid droplets formed
   from $NO2$
- Sulphates and nitrates aerosols (e.g., ammonium (bi)sulphate and ammonium
- nitrate) formed from reactions of sulphuric acid droplets and nitric acid
-   Droplets with $NH3$, respectively
- Organic aerosols formed from VOCs in gas-to-particle reactions

2.4   Methods of emission measurement

A few studies have been undertaken in an attempt to propose the methods of emission measurement of fuels used in rural communities. In contrast, many studies have been carried out on wood burning stoves for heating in homes of the more affluent urban residents (Kulla 2011; Grant and Angela, 2011). The methods can be divided into two broad categories depending on whether they involve direct or indirect measurement of pollutants.

a) **Direct measurement:** Direct measurement of stove emissions involves measurement at the source (the stove). A   hood placed over the stove to

capture emission is frequently used. Butcher et al (1984) attempted to design a low cost simple measurement system for determining simultaneously the emission and efficiency of stoves. The methods involved the direct measurement of   carbon dioxide and total suspended particles passing through a hood at a measured flow rate.

b) **Indirect measurement**: Indirect methods measure the influence of the stove on a dilution chamber (a room simulating a rural dwelling) the emission source strength is calculated by performing a mass balance for the pollutant in the chamber.

3.0   MATERIALS AND METHODS

The area of the study is Aiyetoro Village,Ilorin East Local Government Area of Kwara State. It is located between latitude 13.49N and longitude 8.30E; it is situated in the zone between the northern and southern parts of Nigeria. (Ilorin East,2012). Questionnaires were shared within the community to determine the various types of cooking fuels being used in the village. The fuel samples were collected and burn under normal household cooking conditions to determine the composition of the emitted smoke.

3.1   MATERIALS

GAS ANALYSER

The equipment to be used for the emission analysis is the IMR1400 Gas Analyser (figure 1 below). The IMR Gas Analyser is a state of the art combustion gas analyser that samples emission products directly from the combustion chamber.

Fig 1: IMR1400 Gas Analyser.

3.2 EXPERIMENTAL PROCEDURE

3.2.1 Emission Analysis experiment

The emission test was conducted at the Nigerian Institute of Transport Technology (NITT) in Zaria. The study was conducted to investigate the composition and quantity of gaseous emissions released during combustion of cooking fuels.

Cooking fuels tested are sheabutter fuelwood, locust bean fuelwood, sheabutter charcoal, locust bean charcoal, Dual Purpose Kerosene (DPK) and electricity.

An extraction booth with a cylindrical top was constructed. The cylindrical top permits free draft for easy collection of smoke from the stove. The entire stove and the pots were enclosed in an extraction booth. Booths such as this are typically used for extraction of fumes where a low capture velocity is sufficient and typically of the order of 0.5m/s (Kulla, 2011). Flue gas is removed from the hood through a duct of 200mm diameter. The duct was then connected through the gas-sampling probe into the analyser. The gas sampling probe was at ambient zero calibration. The unit was turned on to start the zero calibration, which took 180 seconds before starting the measurement. The fuel was selected through the selection menu and the reading of the quantity of the emitted gases was recorded for each set of experiments. Each set of experiments was conducted three times and the average reading of the emissions was recorded.

4.0   RESULT AND DISCUSSION

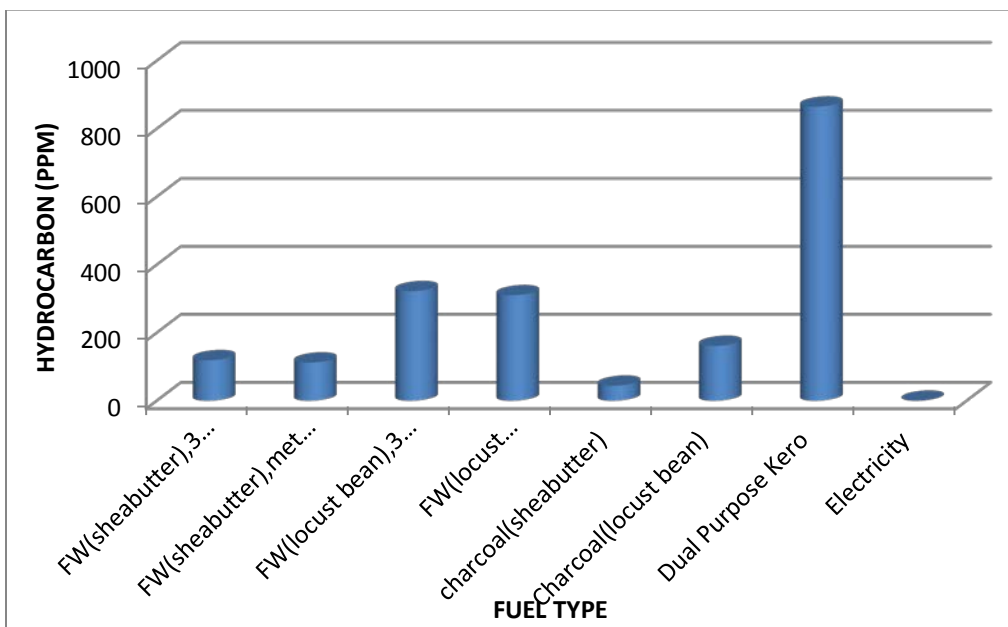The result of the test conducted is given in the figures below:

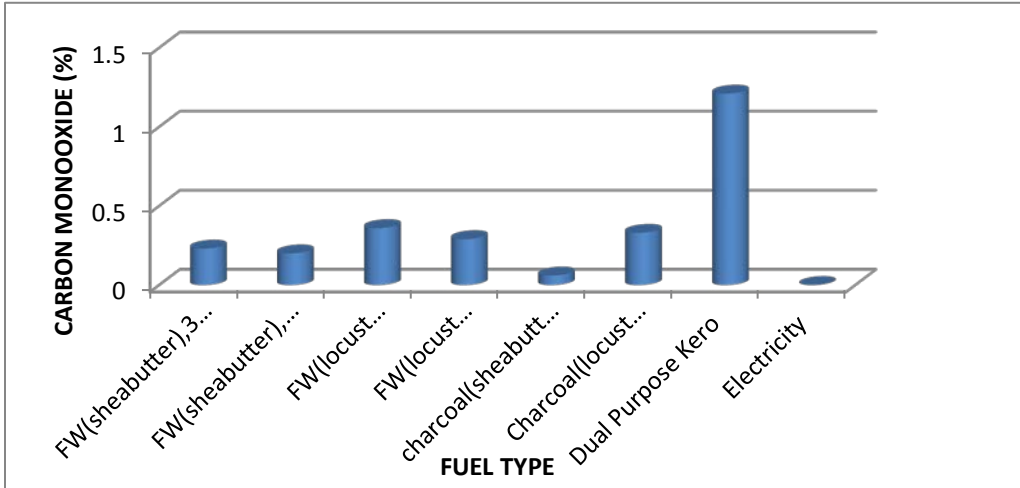Figure 2: hydrocarbon emission from fuel combustion for household cooking

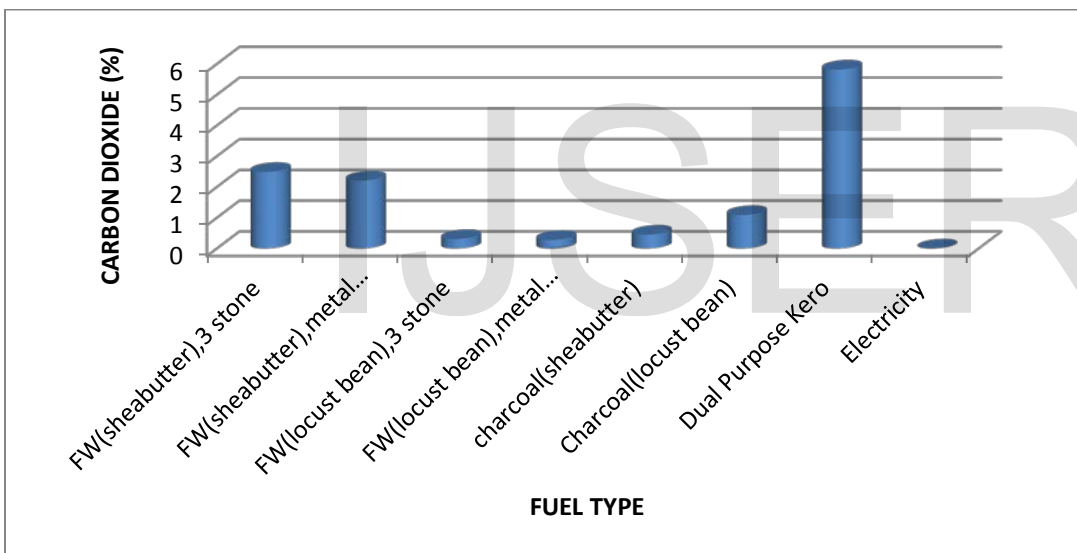Figure 4: CO emission from fuel combustion for household cooking

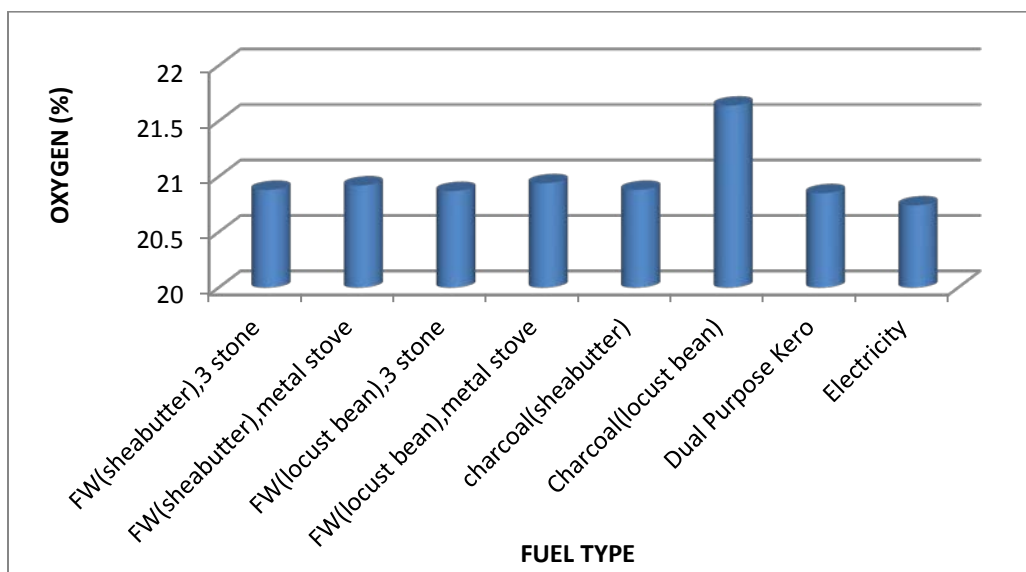Figure 4: CO_2 emission from fuel combustion for household cooking

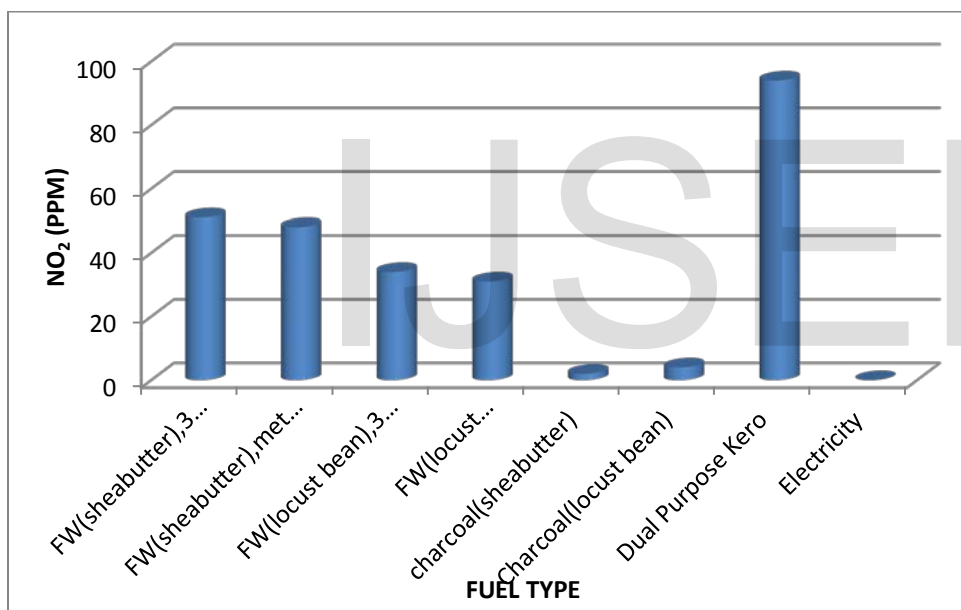Figure 5: O₂ emission from fuel combustion for household cooking

Figure 6: NO₂ emission from fuel combustion for household cooking

The emission measured was composed of hydrocarbon (HC), Carbon monoxide (CO), Carbon Dioxide (CO2), Nitrogen Dioxide (NO2) and Oxygen (O2).

The emission of these gases varies from sheabutter, wood charcoal through sheabutter fuelwood using a metal fabricated stove to sheabutter fuelwood using the 3-stones settings to locust bean wood charcoal to locust bean fuelwood using the metal fabricated stove to locust bean fuelwood using the 3-stones settings to DPK using Kerosene stove in ascending order of magnitude. In all this cases, the emission is usually in

excess of atmospheric air up to 500 times. There was no PIC emission from electric stove.

As observed by Christoffer (2005), the use of upgraded biomass fuels with controlled combustion conditions gives advantageous condition for optimisation of the combustion processes, there was a noticeable reduction in the quantity of emission when metal fabricated stove was used as compared to when the 3-stones setting was employed as well as the reduction in emission between the use of charcoal as compared to the use of fuelwood.

 Similarly, it was observed that sheabutter emits higher carbon dioxide and nitrogen dioxide but lower hydrocarbon and carbon monoxide when compared to emission from locust bean fuelwood. However, carbon dioxide, carbon monoxide and nitrogen dioxide emission tends to be higher in locust bean fuelwood as compared to sheabutter.

5.0   CONCLUSION

The major gaseous emission produced by the combustion of the fuels are; hydrocarbon (Methane), carbon monoxide, carbon dioxide, oxygen and nitrogen dioxide. Dual purpose kero emits more of these gases when compared to the traditional fuels while electricity produces zero emissions. Emission from fuelwood is higher than that of charcoal while emission from locust bean tree is higher than that of the sheabutter tree. The device used for combustion also has a significant effect on the emissions. The metal fabricated stove in which there is a form of oxygen control emits less PIC compared to 3-stones stove where oxygen is not being controlled.

Emission from residential cooking fuels includes a number of air pollutants with potential adverse health effects such as CO, CO2, NO2, and hydrocarbon. These emissions were determined as functions of variation in fuels, appliances and operational properties of the process of combustion. However, these emissions can be controlled by proper technical and/or operational measures and a significant potential for further development and optimisation thus exists.

6.0   RECOMMENDATION

It is hereby recommended as a result of the findings presented in the thesis that :

Research institutes must develop appliances and systems that ensure efficiency in the utilisation of these energy resources especially fuelwood and charcoal, while also reducing the emission produced from their combustion.

Non-Governmental Organisations should sensitize rural households on the short and long term effects of usage and exposure to gaseous emissions while also ensuring the penetration of technology developed by research institutes.

REFERENCES

Butcher S.S, RaoU, Smith K.R, Osborn J, Azuma P & Fields H (1984). Emission factors and efficiencies for small scale open biomass combustion: Towards standard measurement techniques, paper presented at the annual meeting of the American chemical society.

Christoffer B, Anders N, Marcus O & Dan B (2005). Emission from small-scale combustion of biomass fuels- Extensive quantification and characterization retrieved from http://energimyndigheten.se/global/forskning/Bygg/21906-1%20emissions%20from%20small-scale%20combustion%20of%20biomass%20fuels%20-%20extensive%20quantification%20and%20characterization.pdf on 20th December 2012.

Daly, A &Zannetti P (2007). An Introduction to Air Pollution-Definition, Classification and History retrieved fromhttp://environcomp.org/books/chapter/1aap.pdf on 6th December 2012

Dzioubinski O &Chipman R (1999).Consumption and production: Household energy consumption (ST/ESA/1999/DP6) retrieved from www.un.org/esa/sustdev/publications/esa99dp6.pdf on 17th November 2012.

Energy Commission of Nigeria (June 2007).National energy master plan. Abuja, Nigeria: ECN.

Energy Commission of Nigeria (2012).Unpublished draft report of base year (2010) analysis: Model for analysis of energy demand (MAED). Abuja, Nigeria: ECN.

Garba B &Atiku A.T (1997).Thermal studies on some tropical tree species and their performance in improved wood burning stove. Nigerian Journal of Renewable Energy, 5 (1):16-20, Sokoto.

Global alliance for clean cook-stoves: Nigeria market assessment. (2011). retrieved from www.cleanstoves.org/resources_files/nigeria-market-assessment-mapping.pdfon 6th December 2012.

Grant B T & Angela M. (2010). Review of interventions to reduce the exposure of women and young children to indoor air pollution in developing countries. retrieved from www.ecoharmony.com/

Ilorin East Local Government Area (2012) retrieved from http://kwarastate.gov.ng/ilorineast on 6th December 2012.

Kullah D M. (2011), Technology Improvement for safety and economy in wood burning devices in Nigeria, PhD thesis submitted to the post-graduate school, ABU Zaria.

Kulla D.M, Suleiman R.B.O &Ishaya Z.D (2012).PerformanceComparism of different stoves in cooking and heating applications.2nd National Conference & Annual General Meeting of Automobile Engineers Institute. Kaduna.

Regina Bailey. (2010). Carbon Monoxide retrieved from http://biology.about.com/od/molecularbiology/a/carbon_mono xide.htm/

Rehfuess E. (2006). Fuel for life: Household energy &health. Geneva, Switzerland:WHO .

Venkataraman C, Habib G, Eiguren F A, Miguel A H & Friedlander S K. (2005). Residential biofuel in south Asia: Carbonaceous aerosol emission and climate impact retrieved from www.sciencemag.org/content/307/574/1454.full.pdf on 10th December 2012.

World Health Organisation.(2010). Household Use of Solid Fuels and high temperature, IARC Monograph Vol. 95.retrieved from www.monographs.iarc.fr/ENG/Monographs/vol95/mono95-6A.pdf on 17th November 2012

APPENDIX

Result of Emission Gas Analysis

Table A1: Constituents of emitted gas

Emmission	FW 3-stone stove		FW Metal stove		Charcoal		Kerosene	Electricity
	Sheabutter	Locust	Sheabutter	Locust	Sheabutter	Locust		
HC (ppm)	00119	0322	00112	0310	0044	0161	0865	0000
CO (%)	0.23	0.36	0.20	0.29	0.45	1.09	5.82	0.00
CO_2 (%)	2.49	0.31	2.21	0.28	0.45	1.09	5.82	0.00
O_2 (%)	20.88	20.87	20.92	20.94	20.88	21.64	20.85	20.74
NO_2 (ppm)	0051	0034	0048	0031	0002	0004	0094	0000