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COMPARATIVE STUDIES OF EMISSION CHARACTERISTICS OF COMMON COMMERCIAL KEROSENE AND BIOETHANOL COOKSTOVES.

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ABSTRACT

Reliance on inefficient and polluting household fuel such as biomass has significant implication in air quality, thus, affects human health. Alternative to indoor air pollution from inefficient combustion is use of clean cooking fuel such as liquefied petroleum gas (LPG) biogas, ethanol and kerosene with efficient cookstoves. Therefore, this research focuses on bio-ethanol as an alternative fuel to kerosene and other traditional biomass. The experiment was carried out to assess the emission characteristics of common commercial kerosene cookstoves used by local communities and bioethanol cook stove. The combustion reaction of both kerosene and ethanol fuel was evaluated and characterized through different types of kerosene cookstoves and improved ethanol cookstoves. One way analysis of variance (ANOVA) was employed to determine the significant effect of gaseous pollutants emitted from cookstoves at 95% confidence level. The average measured concentrations of HC, CO, NO, NOx, SO_2 and H_2S pollutant from bioethanol cookstove on comparison with different kerosene cookstoves show no significant effect on the surrounding as their p-values ranged from 0.15-1.00.The improved ethanol cookstoves increased thermal efficiency by 19% and 20% and reduced the cookstoves fuel usage by 9.5% and 15%.

KEYWORDS: Air Emission , Analysis of Variance (ANOVA), Bioethanol, Cookstoves, Biomass.

1.0 INTRODUCTION

Renewable energy developments in general and specifically bioethanol covers the advancement, capacity growth and the use of renewable energy sources in sustainable ways. There is a strong link between access to secure sustainable, affordable energy and sustainable development including rural transformation. Frank and Arnaldo (2010) observed that, the desires and necessity to reduce oil import, reducing greenhouse gas emissions, improving air quality and boosting rural economies have been major drivers in promoting ethanol fuels.

The literature on household cooking in developing countries has focused on solid fuels (e.g. wood, dung, charcoal), as they are the most prevalent primary household fuels (Ohimain, 2012). Furthermore, kerosene is often regarded as a “step up the energy ladder” from solid cooking fuels (Smith *et al.*, 1994), and often becomes more prominent as a primary or secondary cooking fuel as countries develop and urbanize. This has been observed, for example, in India, where, kerosene was reported as the primary cooking fuel in 8% of urban households and in <1% of rural households in 2005. Simultaneous indoor and outdoor concentration measurements of kerosene-using houses in India showed indoor/outdoor (I/O) ratios for 12 measured PAH as high as 10.5 (naphthalene) (Pandit *et al.*, 2001 and Raiyani *et al.*, 1993).However, it is often used as a backup fuel in urban areas for when LPG is unavailable and in rural areas for when biomass fuel is unavailable (Rao, 2012).

In Sub-Sahara Africa, an estimated 500,000 people die each year from diseases caused by exposure to Industrial Air Pollution from burning of biomass(Barnes *et al.*, 2005).The combustion of traditional biomass using inefficient cookstoves releases pollutants such as particulate matter, carbon monoxide, oxide of nitrogen, volatile organic compound and polycyclic aromatic hydrocarbon. The quality of pollutants released is highly dependent on the moisture content, oxygen level, type of biomass, combustion temperature and cookstoves configuration.

Exposures to combustion products from solid fuels have been associated with a range of health effects, including lung cancer, chronic obstructive pulmonary disease (COPD), low birth weight, cataracts, pneumonia, and tuberculosis (Fullerton *et al.*, 2008). The health ailment reduces labour productivity and exacerbates poverty. Besides, household incomes are spent on treatment costs, leaving less disposable income to meet other needs. On the other hand, pollutants accumulation results to rise in emissions of greenhouse gases causing global warming. These impacts coupled with the challenges, brings about usage of alternative cooking fuel such as ethanol. In facing these problems posed by the usage of kerosene cookstoves at household levels, this study has been conducted with the aim to compare the emission characteristics of both bioethanol and kerosene cookstoves.

2. MATERIALS AND METHODOLOGY

2.1 Experimental Procedures

The methods involved in carrying out this study includes; identification of various kerosene and ethanol fuel stoves available in Nigeria, the determination of air emissions and also the elemental analysis of the particulates emissions.

2.2 Identification of stoves

The stoves used for this study were obtained from Nigerian market. A total of 10 stoves were used which includes: Jyoti round 1, EMEL 2668, Butterfly 2487, Wheel pressure PS-01.181611, Enamel NR44, Big wheel 641, Star wheel 168, Star wheel NR33, Prince 2053 kerosene stoves and a clean Ethanol cook stove. The specifications such as the stove model, the fuel type used, number of wicks fuel capacity and the net weight of each of the stoves are summarized in Table 1.

Table 1: Stoves Specifications

Stoves	Stove – ID Model	Fuel Type	Number of WICKS	Fuel Capacity (Litres)	Net Weight (Kg)
STV 1	Jyoti Round 01	Kerosene	10	3	2.35
STV 2	EMEL 2668	Kerosene	14	3	3
STV 3	Butterfly 2487	Kerosene	16	1.5	0.9
STV 4	Wheel pressure PS-01.181611	Kerosene	Fire pump	3	2.4
STV 5	Enamel NR44	Kerosene	12	2.5	6.5
STV 6	Big wheel 641	Kerosene	10	2.5	2.3
STV 7	Star wheel 168	Kerosene	8	1.25	
STV 8	Star wheel NR 33	Kerosene	10	1.3	4.5
STV 9	Prince wave	Kerosene	16	3	3.1
STV 10	Clean Cook	ethanol	Improved burner	5	1.5

2.3 Sampling Apparatus

The apparatus used for this experiment were E8500 portable industrial emission analyzer and the Allegro industries D-2 Mold-Lite Sampler P/N 9803-85 series with a 10 mm diameter stainless steel probe. The E8500 portable industrial emission is an analyzer equipped with in-built thermoelectric chiller which efficiently and quickly removes water vapour from gas sample to prevent gases from bubbling from the gas phase into the condensate. This combustion analyzer used has ability to measure gaseous emission including: Oxygen (O_2), Hydrocarbons (HC), Carbon monoxide (CO), Carbon dioxide (CO_2), Oxides of Nitrogen (NO, NO_2 and NOx), Sulfur dioxide (SO_2) and Hydrogen Sulphide (H_2S) while the Allegro is a pump for air sampling which is used to determine the particulate concentration in the air emissions from the burning stoves.

2.4 Air Emission Measurement Procedure

A kerosene stove was filled with 50 ml of kerosene, the stove was ignited and the kerosene introduced into the stove was allowed to burn out completely. During the burning period the gaseous and particulate emission concentrations from the flame of the stove were determined using the E8500 portable industrial emission analyzer and the allegro air sampler respectively. The allegro air sampler collects the particulate emitted from the stove on pre-weighed filter paper. This procedure was repeated for all other kerosene stoves and the ethanol gel stove. During the burning period parameters such as time taken for complete burnout of the fuels, temperature of the flame, ambient temperature and ambient relative humidity were all noted.

2.5 Elemental Analysis of Particulate from the Cook Stoves

Particulates collected on pre-weighed filter papers from the cook stoves were taken to Center for Energy Research and Development laboratory of Obafemi Awolowo University, Ile-Ife, Nigeria for elemental analysis using the Proton Induced X-ray Emission (PIXE) Spectroscopy analysis. PIXE analysis is similar to X-ray Fluorescence Spectroscopy Analysis

(XRF analysis) in that the sample is irradiated by high energy source, in this case high energy protons to remove inner shell electrons.

2.6 Meteorological Parameter Determination

The Kestrel 4000 pocket weather tracker is an easy weather monitoring device that instantly measures environmental condition accurately. It was set up to display the following meteorological parameters: Relative Humidity and Temperature. Measurement with the device was done before and after a stove was consider for the experimental procedure.

2.7 Statistical Analysis

The measured air emissions from each of the cook stoves were subjected to one way ANOVA statistical analysis involving mean, range and standard deviation using Origin Pro version 8.5. Mean comparison test was done to determine the significant level of the gaseous pollutants emitted from the cookstoves using $p<0.05$(95% confidence level) as determinant. The emission factors were also analyzed using t-test samples analysis method. The results were presented in tables and curves for clear understanding.

3. RESULTS AND DISCUSSION

3.1 Gaseous Emissions from the cook stoves

The gaseous emission characterized from the kerosene and bioethanol cook stoves were Carbon monoxide (CO), Nitric oxide (NO), Nitrogen dioxide (NO_2), Oxide of Nitrogen (NOx), Sulfur dioxide (SO_2), Hydrocarbons (HC) and Hydrogen sulfide (H_2S) using the E-instrument E8500 industrial analyzer. The experiment was repeated five times (five experimental runs) and the average measured gaseous emissions from the cook stoves were plotted as shown in Figure 1-6. The mean comparison test done to determine significant difference of emitted pollutant from bioethanol cookstove and other kerosene cookstoves shows that for HC, there was a statistically significant difference in the average pollutant measured from the cookstoves at 95% confidence level ($p \leq 0.05$). This was observed when comparing the different types of cookstoves, but the research aim was to compare bioethanol with kerosene cookstoves. The standard deviations are 388.7, 307.1, 277.8, 683.8, 3239.7, 971.5, 4799.4, 417.4, 1202.3 and 683.7 for STV1, STV2, STV3, STV4, STV5, STV6, STV7, STV8, STV9 and STV10 respectively. Paired samples t-test was used to make the mean comparison between STV10 and the other kerosenecookstoves (STV1-9). The mean differences are 1212, 1496, 1596, 546.8, -2192, 334, -3812, 855.4 and -138.8 for STV10-STV1, STV10-STV2, STV10-STV3, STV10-STV4, STV10-STV5, STV10-STV6, STV10-STV7, STV10-STV8 and STV10-STV9 respectively. These results indicated that HC emission has no statistically significant difference in the types of cookstoves.

The mean comparison test for average measured CO pollutant indicated that there is no significant difference in the emission released by bioethanol cookstoves when compared with other kerosene cookstoves at 95% confidence level. The standard deviations of the measured CO gas from the stoves are 1976.5, 933.1, 2341.1, 2972.6, 2674.2, 817.4, 2537.8, 929.9, 1189.4 and 2361.2 for STV1 to STV10 respectively. There was a significant difference when comparing the different kerosene cookstoves (STV8 with STV6 and STV5, STV7 with STV2, STV6 with STV2&3 and STV5 with STV2&3). For NO gaseous pollutant, the average measured values from STV10 and STV1-9 on comparison shows no significance in the means difference between bioethanol cook stove and different kerosene cookstoves, except STV9 when compared with STV1&3 that shows significance difference in the means comparison. The standard deviations of the measured NO gas for STV1 to STV10 are 1.9, 5.2, 2.4, 24.3, 35.1, 16.1, 24.7, 6.4, 90.4 and 54.7 respectively.

On comparing average measured NOx pollutant from STV10 with different kerosene cookstoves (STV1-9), no significant difference was seen, except the paired sample test between STV10 and STV5which gave a significant difference in the means with p=0.00246. The measured gas standard deviations are 1.9, 5.2, 2.2, 24.8, 37.7, 10.4, 0.9, 30.5, 10.0 and 2.7 for STV1 to STV10 respectively. Also, the mean comparison between STV9&5, STV7&5and STV5 with STV1,2,3 indicated a significance in the means difference. Therefore, NOx measured from bioethanol cookstove was not significantly different from kerosene cookstoves. The average emitted SO2 from the bioethanol cookstove on comparison with all the kerosene stoves indicated no significance in the means difference and the standard deviations are 1.8, 5.2, 8.9, 71.3, 137.9, 79.3, 0.0, 0.0, 19.1 and 81.1 for STV1 to STV10 respectively. Also there was no significant difference in the SO_2 measured from different kerosene stoves on comparison. For H_2S, the average measured values between all the stoves show no significance difference statistically in the mean comparison as p values are 1 and the cookstoves standard deviations for the emitted gas are 4.2, 0.0, 4.0, 7.3, 18.9, 7.0, 19.4, 0.0, 32.1 and 22.2. Generally, the effect of emitted pollutants from bioethanol cookstove (STV10) was not significant.

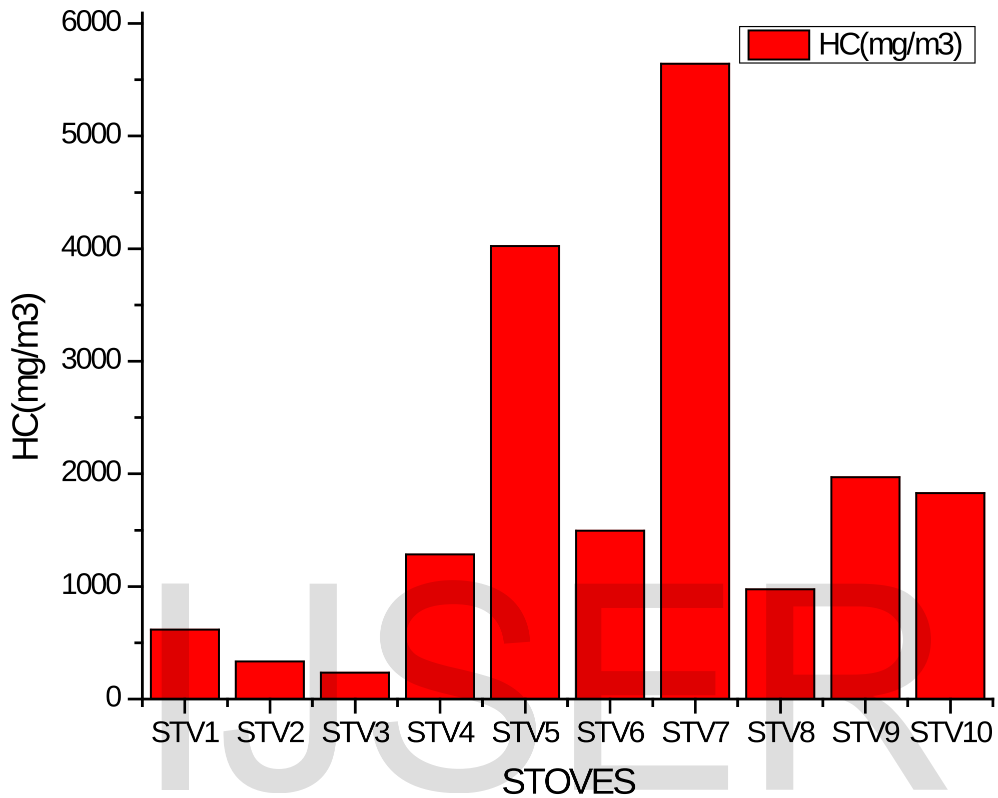

Figure 4.1Average Hydrocarbon (HC) emissions from Kerosene and Bioethanol Stoves

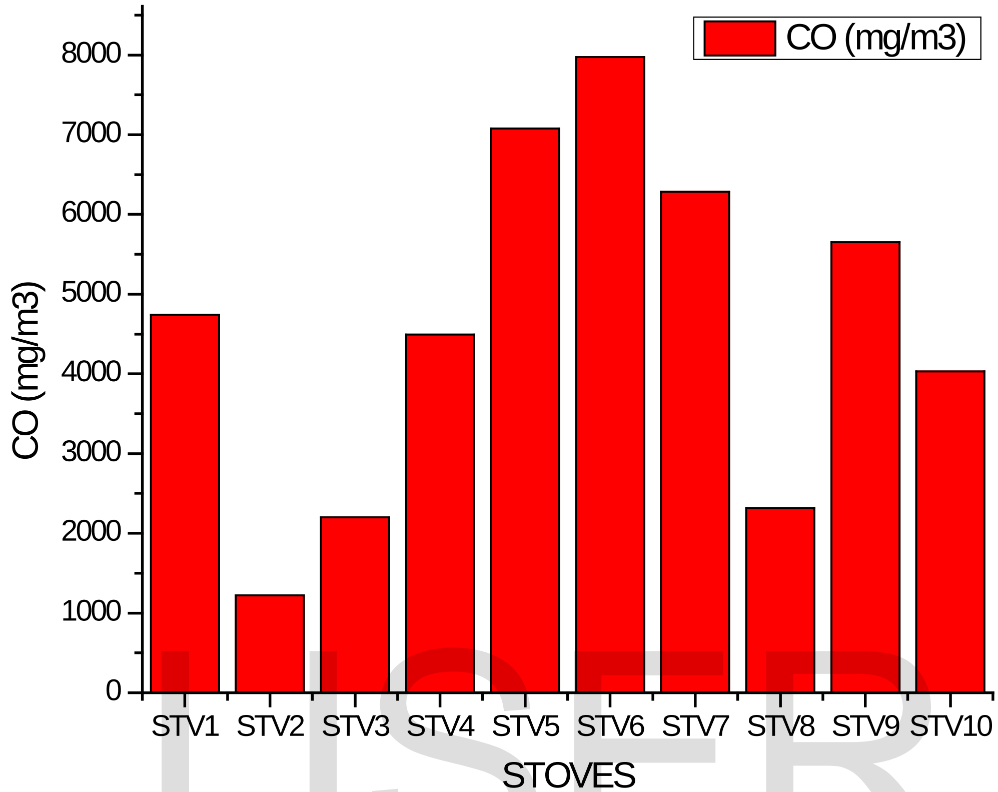

Figure 4.2 Average Carbon monoxide (CO) emissions from Kerosene and Bioethanol Stoves

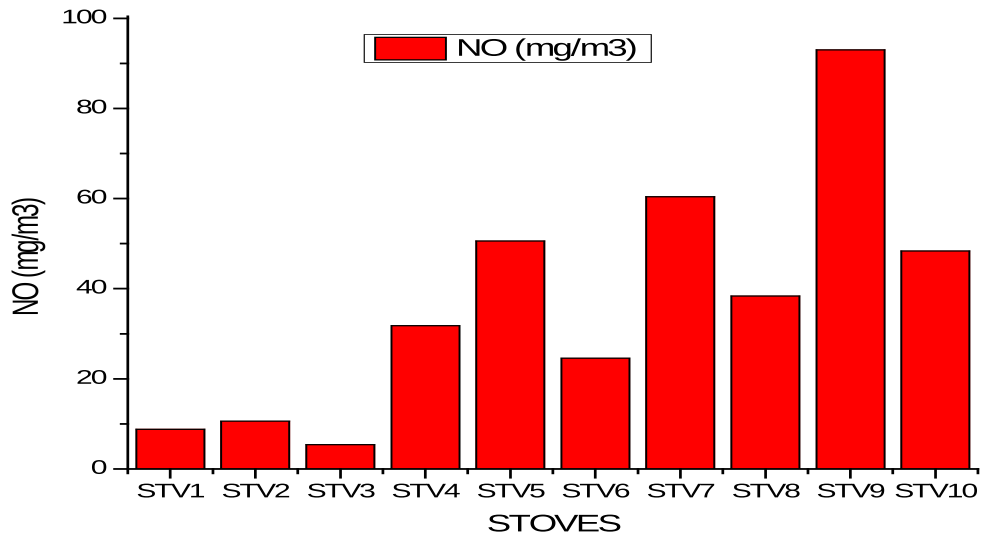

Figure 4.3: Average Nitrogen oxide (NO) emissions from Kerosene and Bioethanol Stoves

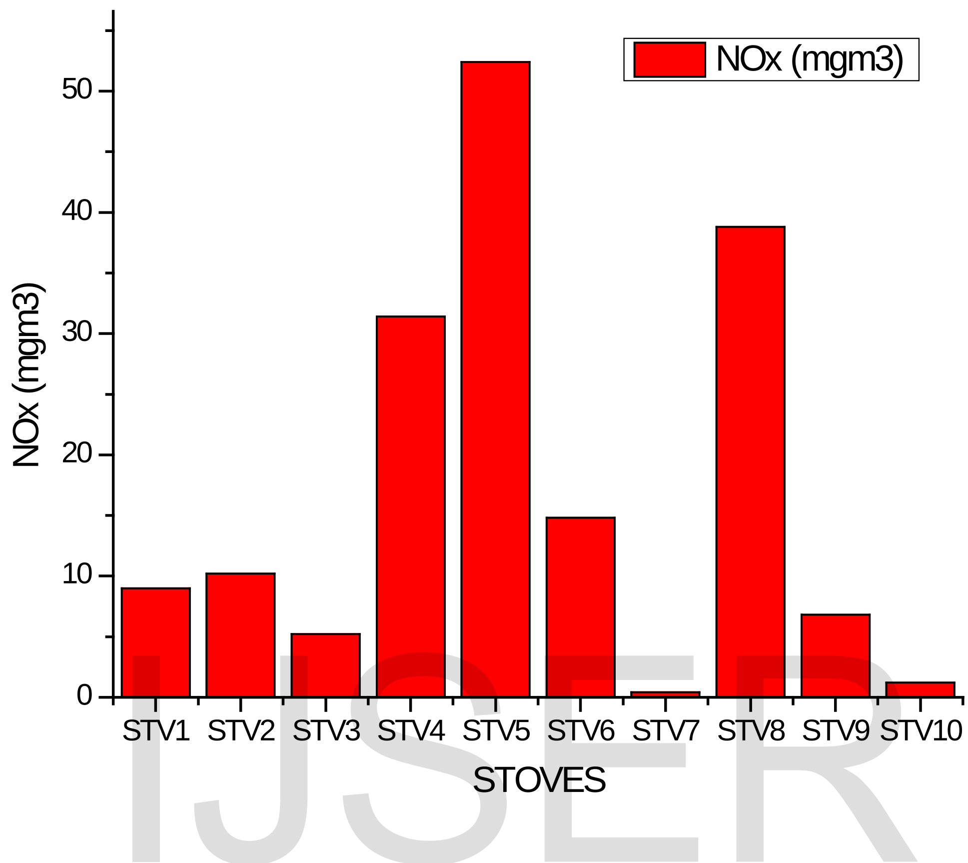

Figure 4.4 Average Oxide of Nitrogen (NOx) emissions from Kerosene and Ethanol Stoves

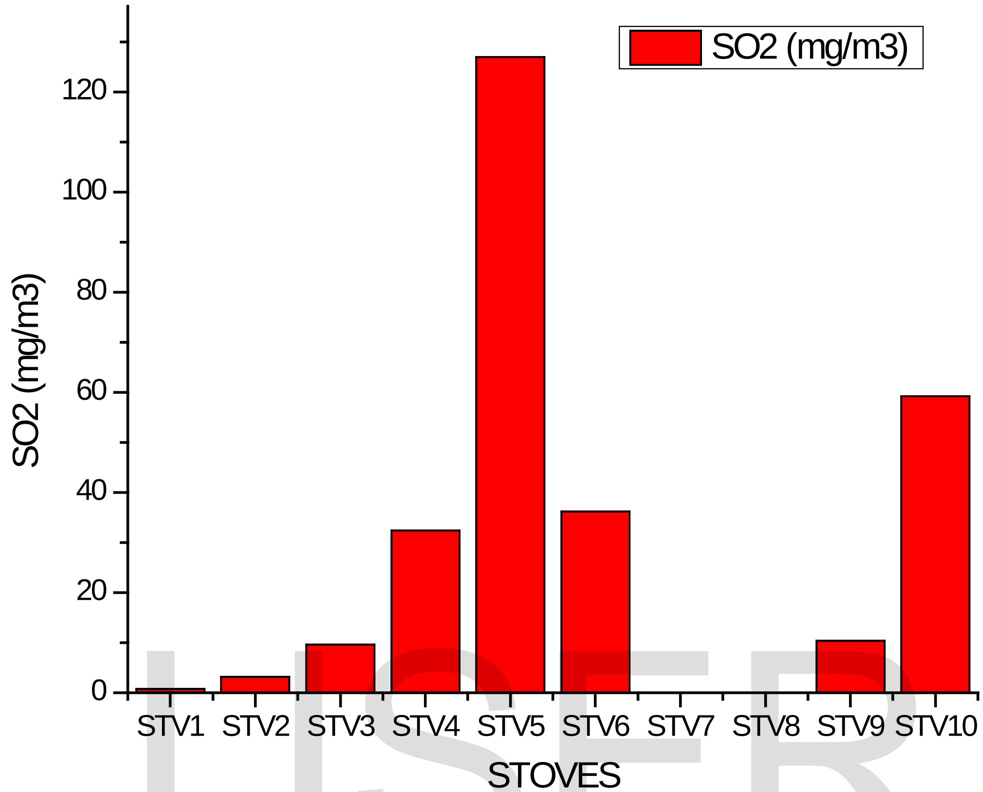

Figure 4.5 Average Sulphur dioxide (SO_2) emissions from Kerosene and Ethanol Stoves

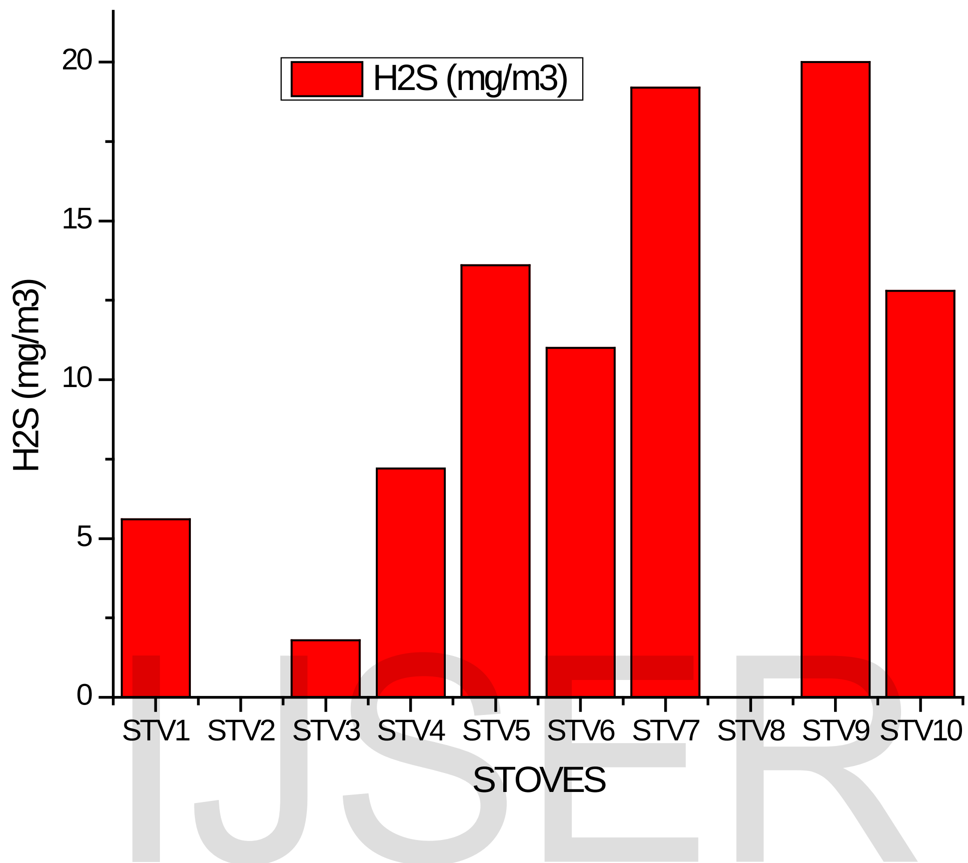

Figure 4.6 Average Hydrogen Sulphide (H_2S) emissions from Kerosene and Ethanol Stoves

3.2 Elemental Analysis of Particulate from the Cook Stoves

The emission levels of particulate matter were collected from the cook stoves. The particle concentrations were range 0.002 – 0.038 g/l with minimum concentration from STV 6, 7 and STV 10; the maximum emitted particulate was from STV S4. The levels of elemental components from each cook STV are presented in Table 4.4. The element detected were Silicon (Si), Sulphur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Iron (Fe), Nickel (Ni), Copper (Cu), Bromine (Br), Aluminum (Al), Zinc (Zn), Manganese (Mn), Chromium (Cr), Lead (Pb) and Titanium (Ti).

The elemental concentrations were range 0.0 – 42.24 g/L for Si, 0.0 – 344.19 g/L for S, 14.67 – 152.72 g/L for Cl, 0.0 – 123.82 g/L for K, 52.96 – 1331.05 g/L for Ca, 4.87 – 67.11 g/L for Fe, 0.0 – 18.0 g/L Ni, 0 – 5.83g/L Cu, 0.0 – 29.26 g/L, 0.0 – 12.31 g/L Al, 0.0 – 12.55 g/L Zn, 0.0 – 7.98 g/L Mn, 0.0 – 2.25 g/L Cr, 0.0 – 37.86 g/L Pb and 0.0 – 7.64 g/L Ti.The elemental concentrations were range 0.0 – 42.24 g/L for Si, 0.0 – 344.19 g/L for S, 14.67 – 152.72 g/L for Cl, 0.0 – 123.82 g/L for K, 52.96 – 1331.05 g/L for Ca, 4.87 – 67.11 g/L for Fe, 0.0 – 18.0 g/L Ni, 0 – 5.83g/L Cu, 0.0 – 29.26 g/L, 0.0 – 12.31 g/L Al, 0.0 – 12.55 g/L Zn, 0.0 – 7.98 g/L Mn, 0.0 – 2.25 g/L Cr, 0.0 – 37.86 g/L Pb and 0.0 – 7.64 g/L Ti.

The elemental composition of particulates matter as detected by PIXE spectroscopy was presented in table 4.11. The elemental analysis show that K, Ni, Cu, Br, Mn, Cr, Pb, Ti were not detected in the ethanol stove emissions (STV 10) but were detected in some of the Kerosene stove emissions, therefore shows the better performance of the ethanol stove over the kerosene stove. Also other elements detected in the ethanol stove were low as compare to other Kerosene stove. This implies that the ethanol stove is cleaner in terms of particulate elemental emissions compared to the kerosene stoves. While measuring the emission, the parameters (flame temperature, time, relative humidity and ambient temperature) measured from the different cookstoves during the burning process and their trend behavior are presented in table 2. Bioethanol cookstove (STV10) shows minimal values when compared with different kerosene stoves, thereby making the stove preferable as it generates little or no hazard.

Table 2: Air Emission Measurement Parameters

STV	Flame Temperature	Time	Relative Humidity	Ambient Temperature
STV 1	627.85	2100	64	30.6
STV 2	587.83	1680	55.5	28.9
STV 3	938.41	1080	73.2	27.1
STV 4	1006.84	1200	55.1	32.3
STV 5	770.5	1740	69.8	27.1
STV 6	741.08	2040	74.1	30.5
STV 7	722.5	1500	40.7	29.8
STV 8	678	1380	73.8	26.4
STV 9	789.91	1140	60.5	29
STV 10	448.92	660	68.4	29.5

4. CONCLUSIONS

The use of bioethanol cookstove for household cooking has been proved efficient and reliable over the common kerosene stoves from this study. The amount of gaseous pollutants emitted from the bioethanol cookstove in comparison with different kerosene cookstoves indicated no significance level of effect on the surrounding. It has less emission of gaseous and particulate pollutant, less elemental composition of particulate and promotes renewable energy usage when compared with kerosene cook stoves. It was observed that kerosene stoves generated more heat than ethanol stove (STV 10) since the flame temperature of the bioethanol stove is lower than that of the kerosene stoves. Thereby resulting in reduction in thermal energy because of fewer number of carbon atoms in the molecules of the ethanol compared to kerosene

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