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Emissions testing of loose biomass in Limpopo Province of South Africa

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Abstract

Southern Africa depends on wood for energy. This affects deforestation and global warming. Loose biomass briquettes can replace round wood and mitigate such problems. Loose biomass derived from agricultural and forestry waste has chemicals like pesticides which can cause unsafe emissions. This paper studies emissions resulting from combustion of such loose biomass collected from Limpopo, a province of South Africa. Twelve loose biomass samples were tested for gases emitted from domestic stove combustion. Exhaust gases were sampled and tested to determine composition and quantities of emitted elements. Both element identification and particulate analysis are reported.

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Keywords: Emissions; gases; Loose Biomass; Biomass Briquettes; Combustion

1. Introduction

Emissions resulting from biomass combustion are characteristic of the material composition. During combustion, gases and particles such as CO, CO2 and NO2, polyromantic hydrocarbons and methane can be emitted. The composition of the emissions depends also on the nature of the combustion i.e. complete or incomplete. These emissions can have an impact on human health. Particulate matter and certain oxides such as sulphur oxides have been known to affect the respiratory system [1]. Emissions in domestic applications have been subjects of a number of investigations. Ravichandran and Corscadden [2], investigated and compared the gases and particulates emitted

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by a domestic wood stove. The aim was to reduce emissions of gases and particulate matter during the combustion of briquettes. Although certain leaching techniques were applied to the fuel, no significant improvement in emissions was obtained. Similar work conducted in Poland using a small retort boiler burning biomass pellets produced from wood, wheat straws and rape straws found that all pellet types emit less CO, but wood pellets produced a high concentration of toxic Formaldehyde and Benzene [3]. Wheat and rape straws also exhibited small VOC concentration in flue gases. Similar work by Boman [4] on round wood and pellets also reported that wood emits high amounts hydrocarbons (VOC and PAH) and particulate matter. Furthermore, pellets were found to have more controllable and optimized combustion with less emissions. Some of the emitted elements can be attributed to chemicals used during production of the biomass. Agricultural loose biomass contains significant amounts of nitrogen mostly due to fertilization. Qian et al [5] investigated the NO emissions of high nitrogen content biomass using ID 0.45m pilot scale vortex fluidized bed combustor (VFBC). Stock material included rice husks, corn and soya beans. The levels of NOX in the emissions could be adjusted by changing combustion parameters of the VFBC.

In India, investigations were conducted to estimate the gaseous and particulate matter produced by garden biomass as fuel combusted inside a SIFT chamber [6]. Stock materials included grass, leaves, twigs and mixed proportions of all products. Results indicated grass to have low emissions, less toxicity and 10% PM of fine particles with 70% respirable particle fraction, leaves had high non-respirable particulate matter. Leaves and twigs had lower emissions of CO, NO, CO2 compared to grass. In Brazil, an investigation on chemical characterization, combustion, gas and particulate emissions between soft wood and hard wood using Data Ram 4 and Cascade Impactor for PM measurement showed that Araucaria (soft wood) has high lignin content which resulted in high CO emissions during flaming [7]. This led to higher concentration of CO2 and NOx compared to hard woods. Similar results were reported by Sultana and Kurma [8] who investigated high lignin biomass pellets developed from agricultural residue. The high emission of nitrogen was attributed to high content of nitrogen from fertilizers. They also reported that pellets showed positive results in terms of potential to offset substantial amount of GHG emissions.

The main challenge with biomass emissions (especially emissions from loose biomass) is the lack of knowledge on potential health implications. Loose biomass has not been effectively used as a source of energy especially in Sub-Saharan Africa which mainly depends on round wood for energy. If rural communities are to harness loose biomass as a sustainable source of energy, more investigations are required to understand the nature and quantities of emissions produced from their combustion. Research estimates at least 13 million deaths per year as a result of three major risk factors which include indoor pollution [9]. Smit et al [10], investigated methods to reduce air pollution from biomass combustion which has been reported to contribute significantly to childhood pneumonia infections in Guatemala. The aim was to assess the impact of using in-door and open fire wood for cooking. The tests consisted of pregnant women and young infants where open fire had a high number of people and in-door with less number of people. The results indicated high infection of pneumonia for infants. It was also reported that the chimney reduced the risk in open fires by a factor of 50% as shown by a significant drop in child mortality.

2. Experimental Program

2.1. Aim of the Investigation

The aim of this investigation was to determine the emissions from combusting loose biomass freely available in a location in the Limpopo region of Northern South Africa.

2.2. Materials

Twelve different types of loose biomass were collected from freely available forest and agricultural residues. These included maize stalks, maize leaves, grass (yellow thatching grass), ground nut stems, ground nut leaves, ground nut shells, wall nut shells, coconut shells, cow dung, sugar cane leaves, blue gum saw dust and Mopani leaves and bark. These materials were collected from Maphophe Village (Vhembe District) and Vuwani Village (Levubu District) located in the Northern Limpopo Province of South Africa.

2.3. Sample Preparation

Loose biomass samples were grouped per their type, placed in the aluminum foil trays for mass analysis and moisture content analysis using a laboratory oven set at 100 ^{0}C. The samples were exposed to this temperature for an hour until the moisture content stabilized. After the moisture content analysis, loose biomass samples were combusted in an Imbawula Entsha stove. 200g samples were used per combustion session.

2.4. Description of Equipment

Imbawula Entsha combustion stove with internal ceramic lining and a built-in air flow nozzle was used for combustion tests (Figure 2(a)). It has a removable cap which allows for airflow control. During combustion testing, the stove was placed on a CBW-15 Adam scale to monitor the burn rate. The scale has a capacity of 15 kg. A fume hood was placed above the stove to collect exhaust gases and particles. It was equipped with emissions sampling pipes (Figure 2(b)) with dilutor and in-line air filters. K-type thermocouples were used to monitor exhaust gas temperatures. They have temperature measurement ranges of 0 to +1100^{o}C for continuous measurements and -180 to +1350^{o}C for short term measurements. Gases collected from the hood were fed to a TSI Dust Trak 8530 for emissions particle size analysis. It has capacity to measure PM10, PM 2.5 and PM 1.0 particle sizes. Two gas analyzers (Testo 35-s) were used for measuring diluted and undiluted particle emissions linked to a computer for data logging (Figure 2(c)).

(a) (b) (c)

Figure 1. (a) Imbawula Entsha under hood (b) Emissions extraction (c) Gas analyzers

2.5. Testing Procedure

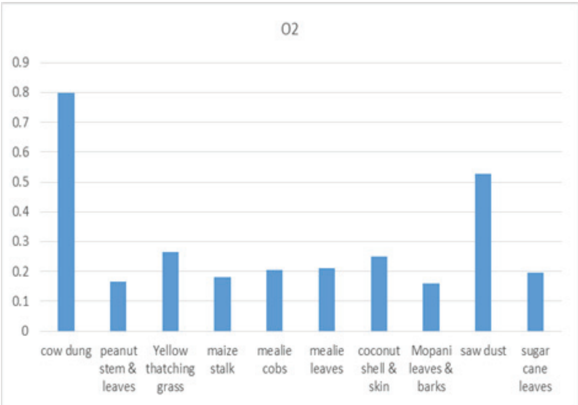
During the combustion of 200 grams of each of the 12 samples, various chemicals emitted were detected with their respective amount of particulate matters. In particular oxygen, carbon monoxide, nitrogen oxide, sulphur dioxide, hydrogen sulphide, hydrogen, nitrogen oxide and carbon dioxide were detected and quantified for each sample.

3. Results

Gases and particulate matter were measured during combustion for the different loose biomass collected in Limpopo. The measured emitted gases are indicated in Table 1. Tested results of gases emitted during combustion varies according to the ratio of chemicals available in that particular loose biomass sample. Seven types of gases emitted were identified and measured in parts per million. The quantities of oxygen reported may also be dependent on the amount of air used during combustion while quantities of carbon monoxide may reflect incomplete combustion. Nitrogen oxides, sulphur oxides and hydrogen sulphides depend mainly on the composition of the material being combusted. Nitrogen oxides may also result from high spot temperatures attained during combustion. These quantities for various samples are plotted in Figure 2.

Table 1. Measured emissions during combustion tests per sample type

SAMPLE	O2	CO	NO	SO2	H2S	H2	NOx	CO2
	%ppm	%ppm	%ppm	%ppm	%ppm	%ppm	%ppm	%ppm
cow dung	0.79881	62.931	0.54007	0	0.001	17.277	0.56703	0.0261
peanut stem & leaves	0.16695	17.2297	0.60551	0.0135	0	5.3254	0.6358	0.019
Yellow thatching grass	0.26403	9.9687	0.38241	0	0	1.8989	0.40158	0.0282
maize stalk	0.18183	17.9169	0.34254	0.002	0	4.466	0.3702	0.0253
mealie cobs	0.20534	15.6231	0.30943	0	0.0002	3.6888	0.32498	0.0279
mealie leaves	0.21148	21.0663	0.41122	0.0006	0	5.1903	0.43176	0.0239
coconut shell & skin	0.25052	18.2151	0.14169	0.0005	0	4.512	0.1488	0.0304
Mopani leaves & barks	0.15963	8.725	0.47874	0.0049	0.00013	1.7171	0.50271	0.0308
saw dust	0.52631	8.8469	0.32634	0.0021	0	1.1793	0.34273	0.028
sugar cane leaves	0.19642	19.1208	0.37923	0.0049	0	3.7866	0.39816	0.0255



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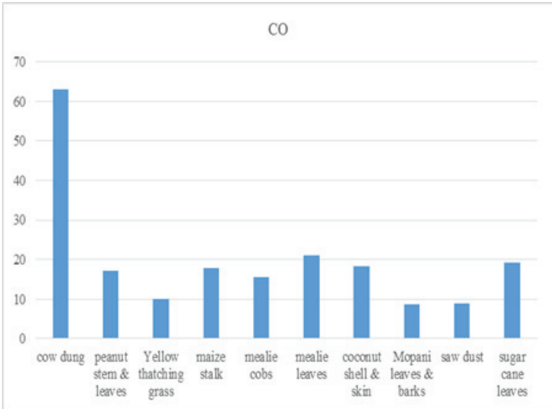

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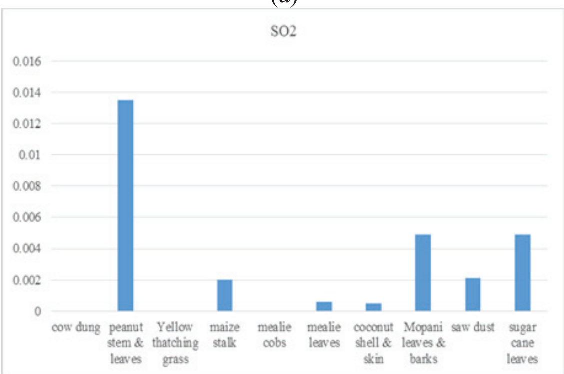

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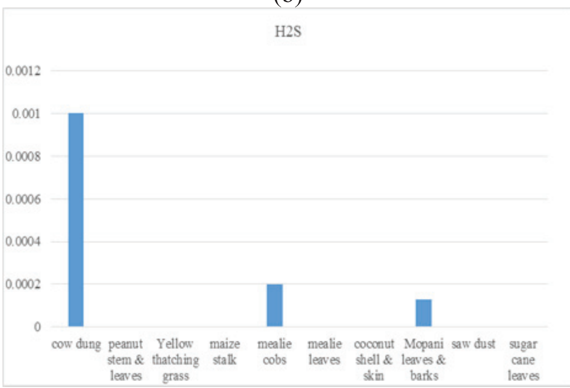

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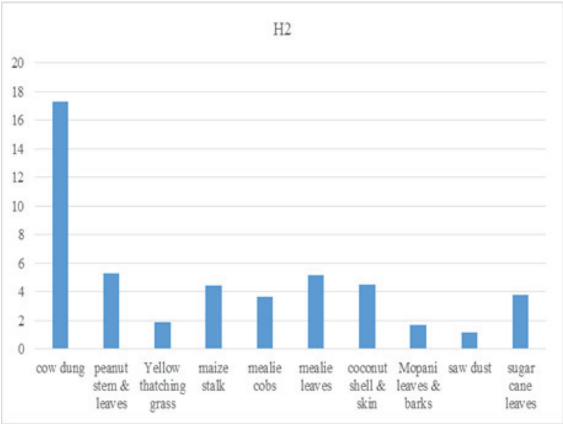

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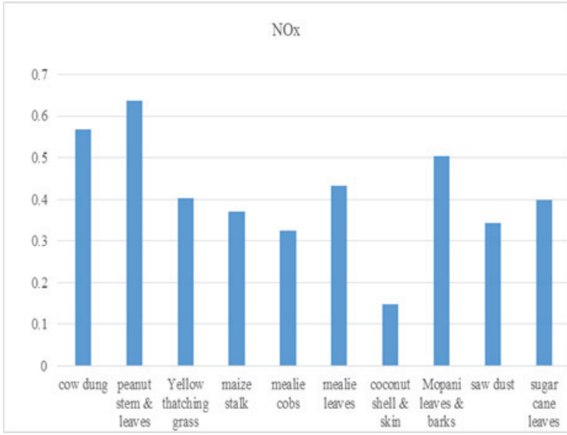

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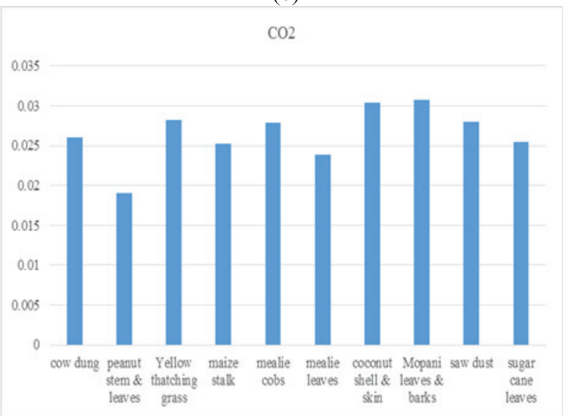

(g)

Figure 2. Emission performance per gas type (a) Oxygen (b) Carbon monoxide (c) Sulphur dioxide (d) Hydrogen Sulphide (e) Hydrogen (f) Nitrogen Oxide (g) Carbon Dioxide.

4. Discussion of results

4.1 Emission content

During emission tests, cow dung registered the highest oxygen content followed by saw dust. Mopane leaves recorded the lowest oxygen content. This is certainly a composition issue since all samples were burnt using the sane stove under the same conditions. Cow dung also reported the highest carbon monoxide followed by maize and sugarcane leaves while mopane leaves also reported the lowest. Sulphur oxides and hydrogen sulphides were highest in cow dung followed by mopane leaves and sugarcane leaves. Significantly, some samples such as grass and groundnut shells did not record any traces of sulphur oxides or hydrogen sulphides. Such materials would be safe to use as they do not produce acids. Highest hydrogen was also recorded in cow dung and lowest in saw dust. Peanut shells recorded the highest NOX followed by cow dung while the lowest NOX was recorded in coconut shells. As expected, carbon dioxide was almost the same quantity in all samples.

4.2 Briquetting Candidates

One of the objectives of this paper is to select loose biomass materials that can be used safely as fuels for domestic heating and cooking. The selected loose biomass would be briquetted and tested for performance. In terms of the measured emissions, the best briquetting candidate materials must have low nitrogen oxides, low sulphur oxides and low hydrogen sulphides. Such materials would have the lowest impact on health and the environment. Peanut stems and leaves, yellow thatching grass and maize stalks and leaves meet this criteria. However, this is not the only criteria for the selection of briquetting materials. Shuma et al [11], investigated the energy content and combustion behaviour of loose biomass available in Limpopo province of South Africa and considered other criteria for briquetting candidate selection. The results indicate that ground nut shells and Eucalyptus saw dust has the highest energy content at 20.3 MJ/kg and 19.97 MJ/kg respectively, furthermore Mopani leaves as a natural available forest residue also recorded high energy content of 18.81 MJ/kg which qualifies these loose samples for briquetting candidates. Calorific values, density, moisture content, availability of the material and burning behavior are important factors to consider.

5. Conclusion

Experimental investigation of gaseous emissions was conducted on twelve samples of loose biomass collected from the Limpopo Province of South Africa. These were the most widely available loose biomass in the region and are natural candidates for biomass briquetting. Emissions from the selected loose biomass were characterized and quantified. Based on the results obtained, the following conclusions can be made:

1. Emissions during the combustion of loose biomass from the Limpopo Province of South Africa were successfully quantified
2. Cow dung recorded the highest quantities of O2, CO, SO2, H2S and H2. This disqualifies cow dung as a good and safe briquetting candidate. However, cow dung has been known to be a good binder during briquetting. In cases where this is the case, other measures must be implemented to dilute the emission concentration to safe levels.
3. The safest briquetting candidates were found to be peanut stems and leaves, yellow thatching grass and maize stalks and leaves. These are recommended for briquetting.

Further work will be required to produce the biomass briquettes using the selected stock materials and test their emissions and combustion behavior before field implementation.

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References

[1] K. Smith and D. Pennise , "Biomass Pollution Basics," Center for Entrepreneurship in International Health and Development (CEIHD), California-Berkeley, 1999.
[2] P. Ravichandran and K. Corscadden, "Comparison of gaseous and particle emissions produced from leached and un-leached agricultural biomass briquettes.," Fuel Processing Technology, vol. 128, pp. 359–366, 2014.
[3] A. Musialik-piotrowska, W. Kordylewski, J. Ciołek and K. Mościcki, "Characteristics of air pollutants emitted from biomass combustion in small retort boiler," environment protection engineering, vol. 36, no. 02, pp. 124-126, 2010.
[4] C. Boman, "Particulate and gaseous emissions from residential Biomass Combustion," Solfjädern Offset AB, Sweden, 29 April 2005.
[5] F. Qian, C. Chyang, K. Huang and J. Tso, "Combustion and NO emission of high nitrogen content biomass in a pilot-scale vortexing fluidized bed combustor," Bioresource Technology, vol. 102, p. 1892–1898, 2011.
[6] G. K. Kannan, M. Gupta and J. C. Kapoor, "Estimation of gaseous products and particulate matter emission from garden biomass combustion in a simulation fire test chamber," Atmospheric Environment , vol. 38, p. 6701–6710, 2004.

[7] S. S. Amaral, J. A. de Carvalho Junior, M. A. Martins Costa, T. G. Soares Neto, R. Dellani and L. H. Scavacini Leite, "Comparative study for hardwood and softwood forest biomass: Chemical characterization, combustion phases and gas and particulate matter emissions," Bioresource Technology, vol. 164 , p. 55–63, 2014.
[8] A. Sultana and A. Kumar, "Development of energy and emission parameters for densified form of lignocellulosic biomass," Energy, vol. 36, pp. 2716-2732, 2011.
[9] A. Prüss-Üstün, S. Bonjour and C. Corvalán, "The impact of the environment on health by country: a meta-synthesis," Biomed Central: Environmental Health, vol. 07, pp. 2-10, 2008.
[10] K. R. Smith, J. McCracken, Hubbrd, A. A. Jenny and L. M. Thompson, "Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial," Lancet, vol. 378, p. 1717–26, 2011.
[11] M. R. Shuma, D. M. Madyira, T. Makonesa and G. A. Ooisthuizen, "Energy content and combustion behaviour of loose biomass available in Limpopo Province of South Africa," International Conference in Dometic Use of Energy, Cape Town, South Africa, 2015.