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COMPARATIVE STUDY OF NON-METALLIC CONTENTS OF SAWDUST OF DIFFERENT WOOD SPECIES AND COAL SPECIES IN NIGERIA

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Abstract

The study assessed the non-metallic contents of sawdust samples by ultimate analysis and compared with those of coal species found in the literature. The results showed that the sawdust of the wood species have: carbon contents ranged from 43.78% for Uapaca heudelotii to 62.95% for Irvingia excels; hydrogen contents ranged from 4.35% for Entada gigas to 7.07% Parkia biglobosa;; sulphur contents ranged from 0.00% for Pterygota macrocarpa to 0.09% Spondias mombin; nitrogen contents ranged between 0.00% for Blighia sapida and 1.70% for Khaya ivorensis, and oxygen contents ranged between 30.08% Macaranga barteri and 50.61% Uapaca heudelotii. It was concluded that utilization of sawdust as energy source has minimal or no environmental concerns, unlike coal.

Keywords: *Biomass; non-metals; sawdust; coal, emissions.*

1. Introduction

In 2012, the electricity generation was 21.6 trillion kilowatt-hours (T-kWh) in the globe and it is expected to rise to 25.8 T-kWh in 2020 and 36.5 T-kWh in 2040 [1]. Hence, net electricity generation of our world will increase 69% by 2040. About 50,000 coal fired power plants were working in 2007, and this total is expected to be on the increase globally [2]. The world is worried about the environmental problems engendered by coal based power plants. The burning of coal produces air pollutant that aid acid rain, global warming, harms to fauna and flora and damage of aesthetics and strength properties. It has been reported that after three decades of regulation, coal-fired power plants were estimated to cause between 10,000 [3] and 30,000 deaths annually [4], due to emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx) and directly emitted particulate matter (PM) [5]. The importance of further reducing emissions from coal-fired power plants have been thoroughly studied [6]. One way to approach this problem is to consider alternative energy sources that will emit less of these pollutants. The present study focuses on finding alternative to coal as a way of minimizing the emission of these pollutants and biomass appears to offer this advantage.

In Nigeria, sawdust, a woody biomass resource is available in large quantity. It is generated during the conversion of log at sawmills, and huge amount is generated due to poor conversion efficiencies of milling machines [7]. Up to 5.2 million metric tons of wood wastes are generated across Nigeria on annual basis [8], with considerable percentage of these coming from the southwestern region of the country. This is so because the region comprises states that are located in the tropical rain belt and therefore houses more forest reserves and sawmills than any other part of the country [8].

Elehinafe *et al.* [9] investigated the calorific values of sawdust of different wood species found in southwestern Nigeria with a view to considering their suitability as energy sources amid energy challenges in the country. The study showed that the energy values of the sawdust samples with about 15% moisture content compared with those of coal reported by GREET [10].

The fact that sawdust of wood species is in abundance in southwestern Nigeria and that the wood species have considerable energy contents to be considered as the source of fuel, they could not but have some degrees of impacts on the environment which definitely would be lower than those of coal. This study was undertaken to assess the non-metallic components: sulphur contents, carbon contents, nitrogen contents, hydrogen contents and oxygen contents of the wood species that could be responsible for emissions of carbon oxides (CO_x), NO_x and SO_x, water vapour ($H_2O_{(g)}$) and oxygen (O_2). The work was done by carrying out the ultimate analysis of sawdust of 100 wood species local to the southwestern, Nigeria. It went further to validate the results with the results of ultimate analysis those of coal species found in the literature in comparative analysis.

2. Methodology

2.1. Sourcing, identification, and pretreatment of sawdust samples

The samples of the sawdust of 100 wood species investigated were collected at selected sawmills in the cities of southwestern Nigeria. For proper identification, the twigs of the parent trees were taken to the herbarium of Botany Department, Obafemi Awolowo University, Ile-Ife, Nigeria. The sawdust samples were properly sun-dried until the moisture contents were low enough in the range of 10 to 15 %, appropriate moisture levels for solid fuel, as recommended by ASTMD2016-25 [11].

2.2. Determination of non-metallic contents of sawdust samples

The targeted non-metallic contents of the sun-dried sawdust samples were carbon, nitrogen, sulfur, hydrogen, and oxygen. The percentages of carbon and hydrogen experimentally determined by Leibig-Pregle method [12]; nitrogen and sulphur contents were experimentally determined by Dumas-pregle method [12] while that of oxygen contents were calculated by difference on dry-ash free basis assuming no ash [13].

2.2.1. Determination of carbon and hydrogen contents of sawdust samples

Carbon and hydrogen contents of the sawdust samples were determined simultaneously by the leibig-pregle method. 1g of each sample was placed in a quartz test tube and burnt off through the absorbents magnesium perchlorate to absorb water and sodium hydroxide to absorb carbon dioxide. The amounts of water and carbon dioxide were determined from the difference between the two weightings, one before the other after the absorption of water and carbon dioxide. The percentage of carbon (%C) and hydrogen (%H) were evaluated using equations 1 and 2, respectively.

$$\%C = \frac{a(0.2727)}{g}\ x\ 100\% \tag{1}$$

$$\%H = \frac{b(0.1111)}{g}\ x\ 100\% \tag{2}$$

where: g = weight of the sample; a = quantity of CO_2; b = quantity of H_2O.

2.2.2. Determination of nitrogen contents of sawdust samples

Nitrogen contents of the sawdust samples were determined by Dumas-Pregle method. 0.2 g of each sawdust sample was mixed with powder of copper oxide in the ignition tube. Air was displaced from the tube by passing it through a stream of CO_2 until minute bubble appeared in the nitrogen flow meter filled with 50% solution of potassium hydride. The weighed sample w was burned off at between 700 and 750 °C in a gas burner and later burned in an atmosphere of CO_2 with the gas cylinder shut off. After ignition, the combustion product was displaced with carbon dioxide into the nitrogen flow meter. The percentage of nitrogen (%N) content was determined by equation 3.

$$\%N = \frac{V(1.097)}{g} \, x \, 100\% \qquad (3)$$

where, V = volume of nitrogen in the nitrogen flow meter; 1.097 = mass of 1mL of nitrogen in the test tube; g = weight of sample.

2.2.3. Determination of sulphur contents of sawdust samples

Sulphur contents of the sawdust samples were determined by Dumas-pregle method. 1g of each sample was wrapped in an ashless filter paper secured in the platinum wire seal into a glass rod held fast to the stopper of a flask filled with oxygen. The weighed sample in the filter was ignited and inserted in the flask immediately, and the flask was plugged with the stopper. The product was absorbed with a mixture of water and hydrogen peroxide to oxidize the combustion product immediately. The combustion product was titrated with a solution of Barium perchlorate in the presence of the indicator Toron to achieve a pH value of 4.5. The percentage of sulphur content was determined by 4.

$$\%S = \frac{(T \, x \, V)}{g} \, x \, 100\% \qquad (4)$$

where, T=Titre of $Ba(ClO_4)_2$ solution; V= volume of $Ba(ClO_4)_2$ solution; g = weight of the sample.

3. Results and discussion

Up to 100 species of wood species were identified to know their botanical names. 98% of the identified wood species were hard woods and means of the percentages of their non-metallic contents were summarized in Table 1. (The means of percentages non-metallic contents of different wood species in Southwestern, Nigeria). There are important differences between hardwoods and softwoods according to their compositions. Hardwoods are, on average, about 10%, denser than softwoods due to higher lignocellulose and fewer moisture contents [14].These make hardwoods more useful for energy generation. So, the needs to investigate their non-metallic contents that could be of environmental concerns by comparing with those of coal species.

Table 1. The means of percentages non-metallic contents of different wood species in Southwestern Nigeria

S/N	Wood species	%C	%H	%S	%N	%O
1	*Albizia gummifera*	51.25	5.73	0.01	0.26	42.75
2	*Pterygota macrocarpa*	50.44	5.60	0.00	0.12	43.84
3	*Irvingia grandifolia*	48.07	6.19	0.00	0.23	45.51
4	*Crassocephalum biafrae*	52.46	5.97	0.05	0.08	41.44
5	*Daniella oliveri*	50.97	4.99	0.01	0.02	44.01
6	*Parkia biglobosa*	53.43	7.07	0.03	0.08	39.39
7	*Daniella ogen*	51.63	5.95	0.01	1.05	41.36
8	*Cola acuminata*	49.78	6.02	0.01	0.21	43.98
9	*Bambusa vulgaris*	48.04	5.62	0.01	0.37	45.96
10	*Entada gigas*	49.21	4.35	0.02	0.04	46.38
11	*Ficus thionningii*	54.43	7.03	0.00	0.55	37.99
12	*Uapaca heudelotii*	43.78	5.42	0.06	0.13	50.61
13	*Symphonia globulifera*	48.00	6.72	0.02	0.41	44.85
14	*Cola millenii*	49.93	7.02	0.01	1.10	41.94
15	*Prunus dulcis*	51.43	5.40	0.05	0.80	42.32
16	*Entandrophragma cylindricum*	46.17	4.90	0.01	0.10	48.82
17	*Irvingia excelsa*	62.95	4.99	0.01	0.12	31.93
18	*Milicia excels*	44.55	6.12	0.05	0.51	48.77
19	*Delonix regia*	51.88	5.99	0.00	1.63	40.50
20	*Ficus carica*	57.29	6.21	0.01	0.20	36.29
21	*Astonia boonei*	49.29	6.06	0.01	0.40	44.24
22	*Newbouldia laevis*	51.63	4.89	0.03	0.59	42.86
23	*Cassia fistula*	48.82	7.06	0.01	0.35	43.76

S/N	Wood species	%C	%H	%S	%N	%O
24	*Brachystegia leonensis*	54.02	5.49	0.02	0.43	40.04
25	*Musanga cecropiodes*	49.99	5.00	0.01	0.01	44.99
26	*Asteromyrtus symphyocarpa*	51.17	6.29	0.00	0.97	41.57
27	*Poga oleosa*	50.64	5.27	0.02	1.32	42.75
28	*Tectona grandis*	47.96	5.73	0.01	0.04	46.26
29	*Pycananthus angolensis*	51.46	6.06	0.08	0.02	42.36
30	*Gmelina arborea*	46.45	5.31	0.01	0.19	48.04
31	*Parkia biglobasa*	58.04	5.89	0.01	0.74	35.32
32	*Anthocleista vogelii*	44.79	5.68	0.02	0.59	48.92
33	*Afromosia elata*	51.03	5.79	0.00	0.41	42.77
34	*Isoberlina doka*	4.8.84	6.04	0.07	0.11	44.94
35	*Mitragyna ciliata*	52.24	5.10	0.01	0.10	42.55
36	*Blighia sapida*	61.84	6.11	0.01	0.00	32.04
37	*Nauclea diderrichii*	45.47	7.07	0.01	0.74	46.71
38	*Cissus adenopoda*	51.94	6.18	0.00	1.31	40.57
39	*Antrocaryon micraster*	50.38	5.32	0.04	0.51	43.75
40	*Garcinia kola*	_56.07	4.39	0.01	0.01	39.52
41	*Lecaniodiscus cupanioides*	45.95	4.90	0.01	1.60	47.54
42	*Nesorgodonia paparivera*	50.10	5.14	0.00	0.08	44.68
43	*Erythrophylium sp.*	53.56	6.85	0.01	0.13	39.45
44	*Khaya ivorensis*	50.98	5.62	0.01	1.70	41.69
45	*Ficus mucuso*	47.97	5.79	0.06	0.93	45.25
46	*Anogeissus leiocarpus*	50.58	5.28	0.02	0.51	43.61
47	*Chrysophyllum africanum*	51.59	6.19	0.01	0.03	42.18
48	*Pterocarpus erinaceus*	49.87	5.39	0.07	0.57	44.10
49	*Adansonia digitata*	51.04	5.53	0.00	0.26	43.17
50	*Vitellaria paradoxa*	45.96	5.92	0.02	1.01	47.09
51	*Mangifera indica*	58.11	6.39	0.01	0.31	35.18
52	*Cylicodiscus gabunensis*	47.10	5.85	0.01	1.00	46.04
53	*Antiaris Africana*	51.99	5.40	0.01	0.80	41.80
54	*Triplochoton scleroxylon*	48.05	6.46	0.00	0.20	45.29
55	*Hildegardia barteri*	61.41	5.87	0.00	0.50	32.22
56	*Hymenocardia acida*	51.92	5.54	0.03	0.09	42.42
57	*Gliricidia sepium*	47.03	5.40	0.00	0.08	47.49
58	*Diospyros crassiflora*	51.09	6.02	0.01	0.39	42.49
59	*Terminalia ivorensis*	51.57	4.91	0.01	0.71	42.80
60	*Spondias mombin*	58.03	6.04	0.09	0.39	35.45
61	*Pterocarpus osun*	51.58	5.63	0.02	0.01	42.76
62	*Bombax buonopozense*	61.58	5.91	0.00	0.63	32.29
63	*Chasmanthera dependens*	55.07	5.79	0.01	0.29	38.84
64	*Mansonia altissima*	47.01	5.86	0.00	0.13	47.00
65	*Napoleona vogelii*	58.70	6.03	0.01	0.15	35.11
66	*Pinus ponderosa*	52.83	5.52	0.02	0.97	40.66
67	*Citrus limon*	50.58	5.80	0.01	0.81	42.80
68	*Funtumia elastic*	51.02	6.07	0.02	1.03	41.86
69	*Quecus robur*	49.04	5.77	0.01	0.91	44.27
70	*Terminalia glaucescens*	45.06	5.61	0.01	1.60	47.72
71	*Swieteni sp.*	58.96	6.00	0.00	0.70	34.34
72	*Citrus aurantifolia*	46.65	5.40	0.00	1.03	41.86
73	*Bytraria marginata*	51.30	4.92	0.06	0.43	43.29
74	*Azadirachta indica*	48.92	6.10	0.01	0.23	44.74
75	*Macaranga barteri*	62.26	7.02	0.03	0.61	30.08
76	*Sterculia rhinopetala*	61.87	5.39	0.01	0.59	32.14
77	*Berlinia grandifolia*	47.90	5.64	0.01	0.69	45.76
78	*Bombax ceiba*	51.19	6.22	0.00	0.31	42.28
79	*Theobroma cacao*	50.83	5.88	0.00	1.66	41.63

S/N	Wood species	%C	%H	%S	%N	%O
80	*Terminalia superb*	59.03	6.03	0.02	0.79	34.13
81	*Lovoa trichlioides*	50.93	5.50	0.02	1.21	42.34
82	*Citrus medica*	59.73	5.49	0.00	0.00	34.78
83	*Percuguaria daemia*	54.07	5.30	0.01	0.04	40.58
84	*Zanthozylum leprieuril*	46.92	4.98	0.00	0.01	48.00
85	*Elaeis guinensis*	52.06	5.83	0.00	0.13	41.98
86	*Citrus paradise*	55.04	5.29	0.10	0.64	38.93
87	*Ricinodendron heudelotti*	61.50	5.70	0.00	1.00	31.80
88	*Raphia Africana*	53.96	5.90	0.01	0.92	39.21
89	*Phoenix dactylifera*	46.30	7.02	0.02	0.43	46.23
90	*Hevea brasiliensis*	44.05	6.250	0.00	0.88	48.82
91	*Cocos nucifera*	57.02	5.65	0.01	0.49	36.83
92	*Strychnos spinosa*	45.54	5.36	0.02	0.94	48.14
93	*Ceiba pentandra*	51.95	6.21	0.01	1.03	40.80
94	*Piptadeniasrum africanum*	48.98	5.81	0.01	0.01	45.19
95	*Cordia milleni*	61.03	5.40	0.00	0.07	33.50
96	*Cola nitida*	59.94	6.15	0.01	1.32	32.58
97	*Cleistopholis patens*	46.91	5.90	0.02	0.03	47.14
98	*Strombosia pustulata*	54.04	5.83	0.00	0.89	39.24
99	*Artocarpus altilis*	51.91	5.90	0.02	0.71	41.46
100	*Anacardium occidentale*	56.08	5.81	0.02	0.54	37.55

The results of the analysis showed that the sawdust of the wood species has lower carbon contents ranging from 43.78% to 62.95% than coals which ranged between 59% and 84.7% [15]. Carbon dioxide is produced when the carbon in organic fuels is burnt in the presence of oxygen. Carbon dioxide is an essential component for the vital photosynthesis on the planet and is by itself harmless for humans and animals. However, higher concentration in the atmosphere of CO_2 contributes to the greenhouse effect and the higher the carbon content of a fuel, the higher the CO_2 produced [16] in complete combustion. Wood species burning emit carbon dioxide when burned but if the same amount is replanted after harvesting, the net emission can be considered to be zero. In this study, carbon dioxide emissions from burning sawdust for heat and electricity generation will be assumed to be zero. Burning fossil fuels, i.e. lignite, coals, crude oil, and natural gas increases the amount of carbon dioxide in the atmosphere as the anthropogenic use is much faster larger than reproduction of these fuels that takes millions of years.

The sawdusts have higher hydrogen contents ranging from 4.35% to 7.07% compared to coal which ranged between 2.6% and 4.68% [15]. Hydrogen, like carbon, is a major combustible constituent of a fuel. Of the organic component, hydrogen is the third major constituent, comprising typically 5 to 6% dry matter [17]. The combustion of hydrogen yields steam that has no negative impact on the environment. Heating value is also correlated to the presence of hydrogen [17]. Hydrogen also has an effect of increasing the heating values of organic fuels, thereby making sawdust easier to ignite and burn.

The sawdust has lower sulphur contents ranging from 0.00% to 0.09% than the coal species whose sulphur contents ranged between 1.1% and 1.9% [15]. Sulfur oxides (SO_x) are produced when fuels containing sulfur are combusted. This SO_x is an air pollutant that causes acidification, destruction of aesthetics of buildings and is hazardous to human and animal health [18]. Its emission from biomass is mild and when well dispersed, have no negative effect on the environment [16]. It dissolves in rain water to form sulphurous and sulphuric acids. These form sulphates in the soil to increase its fertility [16]. SO_x emission from coals produces acids of sulphur dioxide (SO_2) and sulphur trioxide (SO_3) which corrode the equipment and also cause atmospheric pollution with the symptoms of increase in the severity and incidence of respiratory symptoms of those living nearby, particularly children with asthma and poor visibility. For adults and children who are susceptible, inhalation of SO_x causes inflammation and hyper-responsiveness of the airways, aggravate bronchitis, and decreases lung function (United States Environmental Protection Agency [21].

The sawdust has nitrogen contents ranging between 0.00% for *Citrus medica*, and *Blighia sapida* which are from hardwoods, from the family of *Rutaceae,* and 1.70% for *Khaya ivorensis*, a softwood, while those of coals ranged between 1.00% and 1.70% [15]. Nitrogen has no calorific value and no significant impact on the calorific values of biomass [20]. In the combustion of biomass, nitrogen oxides (NO_x) emissions are produced which when well dispersed have no negative impact on the environment [16]. The emission produces acids of nitric oxide (NO) and nitrogen dioxide (NO_2) in the rain, and these acids form nitrates and nitrites in the soil, thereby increasing the fertility of soil [20]). Combusting coals leads to nitrogen oxide emissions, which contribute to smog formation and particulate formation in the atmosphere that have negative effects on the respiratory system [19] . Nitrogen oxides also lead to acid rain that can damage plant and corrode infrastructure and materials [21].

The sawdust has higher oxygen contents ranging between 30.08% and 50.61% in this study than coals that ranged between 1.60% and 9.00 % [15]). Oxygen contents of fuels generally have not been proven to have negative impacts on the environment in the literature. Heating value is also correlated to the presence of oxygen in organic fuels [17]. Oxygen contents have an effect of decreasing the heating values of fuels depending on the degrees of oxidation. Due to the carbohydrate structure, biomass is highly oxygenated with respect to conventional fossil fuels including coals, hydrocarbon liquids and natural gas [17]. This study shows typically that 30.08% to 50.61% of the dry matter in sawdust of different wood species, in Southwestern Nigeria, is oxygen.

4. Conclusion

The study revealed that carbon dioxide emission (CO_2) from burning sawdust for heat and electricity generation is assumed to be zero. Hydrogen has an effect of increasing the heating values of organic fuels, therefore, making sawdust of wood species easier to ignite and burn and its combustion yields steam ($H_2O_{(g)}$) that has no proven negative impact on the environment. Sulphur yields SO_x while nitrogen yields NO_x and their emissions from burning of biomass are mild and when well dispersed, have no negative effect on the environment. Due to the carbohydrate structure, biomass is highly oxygenated with respect to conventional fossil fuels including coals, hydrocarbon liquids and natural gas. Oxygen contents of biomass generally, have not been proven to have negative impacts on the environment in the literature.

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