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Evaluation of Fuel Properties of Blended Woody Biomass Using Bench-Scale Proximate Analysis

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Abstract **Original Research Article**

As part of the efforts to meet the global energy requirement occasioned by population and economic growth, researchers from different parts of the world have explored various means of power generation in order to provide alternative sources of energy to the conventional fossil fuels and one of the most viable alternatives is the use of woody biomass and the feedstock used in this research is blended Ghana Obeche (Triplochiton Scleroxylon) softwood sawdust as a source of green energy. This research evaluated some fuel properties such as volatile matter (80.04 %wt.), ash content (0.38 %wt.), fixed carbon (8.30 %wt.), moisture content (11.28 %wt.) and heating value (29.65 MJ/Kg) using proximate analysis. Also examined was lignocellulosic composition of the feedstock which was performed using the BABAB, viscose, acid-insoluble test and Soxhlet extraction methods and the results for the cellulose, hemicellulose, lignin contents, water and ethanol soluble extractives of the studied sample were 32.3wt%, 13.2wt%, 20.5wt%, 2.045wt% and 0.918wt% respectively and the values fall within the Austria and Germany DIN51731 and IAEA-C3 standards for measuring wood fuel performance. Triodide-phosphoric acid stain test was used as a confirmatory test for cellulose and the effect of the test on the extracted samples at different time intervals confirmed the authenticity of the extracted cellulose samples as experimented. The percentage of the cellulose and other major constituents confirmed the suitability of the researched sample to produce high yield of bio-fuel during fast pyrolysis if used as feedstock.

Keywords: Fuel properties, lignocellulose, extractives, sawdust, confirmatory stain test.

1. INTRODUCTION

As the global economy grows on a daily basis, energy requirements and utilization have tremendously increased particularly in developed and some developing countries like Nigeria. Presently, the world is being challenged by huge shortages and unstable price of fossil fuels at the international market, a potential solution to the rapid energy demand is the use of lignocellulosic materials such as wood sawdust as renewable source of energy.

Considering the fact that the fossil fuel as the major source of energy is on the decline and fast becoming a topical issue that requires an urgent attention as a result of environmental danger and hazards associated with its exploration and production and judging by the projection that the wood fuel demand would rise to about $213.4x10^3$ metric tonnes by year 2030. As a result of this, a transition to renewable energy alternative is urgently needed in a developing nation like Nigeria (Stout and Best, 2001). Some of the dangers and threats associated with fossil fuel include climate change which is related to carbon emissions into the atmosphere, depletion of ozone layer which results to the emission of ultra-violet radiation of the sun that is harmful to both human and aquatic lives, air and water pollution as a result of release of oxides of sulphur and carbon and other gases into the atmosphere which may cause acid rain and so on. The quest for alternative source of energy has attracted considerable interests in the last decades on the need for the development of environmental friendly renewable sources like wood sawdust and new technologies such as fast pyrolysis process through which organic components of wood sawdust that is, cellulose, hemicellulose and lignin are thermally decomposed when subjected to a high temperature. The product of the fast pyrolysis process is Bio-oil which is a dark brown viscous, acidic with distinctive smoky odour used as fuel for boilers, gas turbines, diesel engines, furnaces and stationary engines (Elliot 2007, Ozbay and Putun, 2006).

Furthermore, the vast availability and abundance of this lignocellulosic material, wood sawdust and its conversion to bio-oil as a sustainable and cheap resource with huge prospect when compared to fossil fuels has made it a viable alternative source of energy supply (Kumar et al, 2009, Gomez and Clare, 2008). It is in response to this challenge and threats posed by environmental degradation and climate change as a result of fossil fuels exploration activities, that this research work sought to determine some fuel properties such as volatile matter, ash content, moisture content, fixed carbon, density, porosity and cellulose yield of Ghana obeche softwood (*Triplochiton scleroxylon*) sawdust and see how efficient and viable its properties are as an alternative source of energy.

There are three major components that constitute wood sawdust namely cellulose, hemicelluloses and lignin and some minor composition of compounds such as lipids, proteins, simple sugar, water, starches, and hydrocarbons and ash (Cheng et al, 2011, Dagnino et al, 2013). It is also often referred to as a lingocellulose substance because it contains lignin and cellulose respectively.

Cellulose is a glucose-based polysaccharide and it has repeating unit of the cellulose polymer with two glucose anhydride units, called cellobiose. It has the general formula $(C_6H_{10}O_5)n$ and they are bonded by covalent bond, hydrogen bond and Van Der Waals forces within the polymer (Agbor et al, 2011).

Cellulose is a major constituent in the production of bio-oil where it usually decomposes to sugars and water. The chemical structure of cellulose is represented by the Figure 1. Volatile compounds are formed when sawdust is being combusted under suitable conditions due to the high content of cellulose in it.

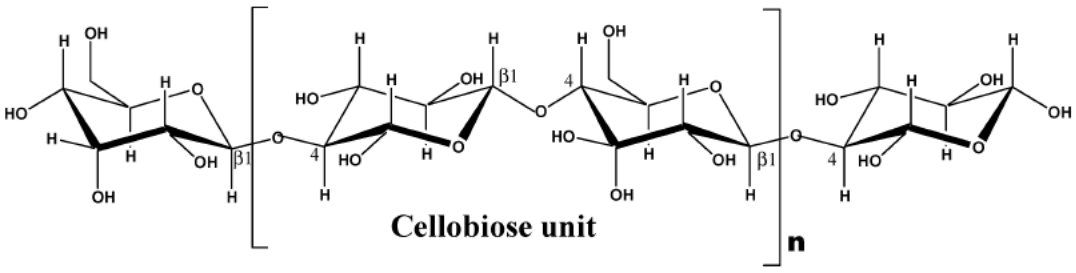

Figure 1: Chemical structure of cellulose (Mohan et al, 2006)

Hemicelluloses are other constituents of wood sawdust which are amorphous polymers of xylose and arabinose. They are chemically heterogenous and contain D- and various O – methylated sugar (Agbor et al, 2011, and Chandra et al, 2007).

Hemicellulose is known to be the most abundant polysaccharide in nature after cellulose and it is colourless. It has the general formula $(C_5H_8O_4)n$ (Yaman, 2004) and they have molecular weights are usually lower than that of cellulose (Dagnino et al, 2013, and Agbor et al, 2011). Hemicellulose generated bio-oil (most acids) yields are much lower and produces significant quantities of char and gas (Shen et al, 2010). The third major component of sawdust is lignin. It constitutes about one-quarter to one-third of the mass of dry sawdust and as a result of its size adds strength to the sawdust. Lignin has no definite structure and is an amorphous cross-linked resin (Mohan et al, 2006). Lignin is more difficult to dehydrate than cellulose or hemicelluloses.

1.2 Some physical properties of wood sawdust

Physical properties that are useful in determining the physical and chemical characteristics of wood sawdust include density, porosity, sphericity, particle size, colour etc.

A. Density

Density can be defined as a measure of the mass of sawdust per unit volume. Also, dry bulk density is defined as mass of oven dry wood per unit of green bulk volume.

B. Volatile Matter

This is a physical property of wood sawdust that helps in determining the combustibility of biomass sample. Volatile matter describes the type of the flame produced during combustion. (Clarke and Petro, 2011).

C. Ash Content

Wood sawdust ash is simply defined as the powdery substance that is left after subjecting the biomass sample to a high temperature in an oven or furnace. It is one of the physical properties of wood sawdust that determines the carbon content of the wood. (Clarke and Petro, 2011). A biomass with high ash content that is rich in metal alkali may cause fouling.

D. Moisture Content

Moisture ordinarily means wetness especially as droplets of condensed or absorbed liquid or in a vapour according to Encarta Dictionaries. But fuel moisture content is normally reported as the wet weight basis moisture content.

E. Porosity

Porosity of sawdust can be defined as a measure of void volume of sawdust grains, composed principally of inter-spaces among the intra-spaces within the particles. (Baker et al, 1998).

2. MATERIALS AND METHODS

2.1 Collection of Raw Materials: The sawdust sample used for this experimental analysis is Ghana Obeche (*Triplochiton scleroxylon*) softwood sawdust. The sample was obtained from Sapele sawmill, Sapele, Delta State and Iloabuchi sawmill in Port Harcourt, Rivers State, Nigeria. It was then bagged and transported to the Petroleum Technology Development Fund (PTDF) Bio-oil Research Laboratory, in the Department of Chemical Engineering, University of Port Harcourt and stored at room temperature for pretreatment and further analysis.

2.2 EQUIPMENT, APPARATUS AND REAGENTS

Several Equipment, Apparatus and Reagents were used in the course of this experimental research such as Soxhlet extraction apparatus, muffle furnace, precision balances, P^H meter, gas cylinder, metallic stand glass ware etc. Several reagents were used to perform the extraction of cellulose and other constituents of the experimental samples. These reagents used include; Hydrogen chloride (HCl), Sodium hydroxide (NaOH),

Hydrogen sulphate (H_2SO_4), Sodium chlorite ($NaClO_2$), Ethanol (C_2H_5OH), Distilled water, PH

test papers, Filter papers, Beakers, Glass cylinders, Test tubes, boiling chips and tubing.

2.3 PROXIMATE ANALYSIS

The following analysis; percentage volatile matter, percentage moisture content, percentage ash content, percentage fixed carbon, heating value, density and porosity were performed in accordance with the methods described by Joseph et al (2012).

2.3.1 PERCENTAGE VOLATILE MATTER (PVM):

To determine the PVM of the sample, 2g of sawdust sample was measured into a crucible and weighed to the nearest 0.001g. The sample was then ashed at 550 ± 5^0C for 10minutes in the muffle furnace. The crucible was removed and cooled in a desiccator. Thus:

$$PVM = \frac{(A-B)}{M} \times 100 \qquad (2.1)$$

Where A = the weight of the oven-dried sample (g)

B = the weight of the sample after 10mins in the furnace at 550^0C. M = the weight of the sample as received (g)

2.3.2 PERCENTAGE MOISTURE CONTENT (PMC)

To obtain the PMC of the sample, 2g of sawdust sample was measured into a porcelain crucible and oven-dried at 105 ± 5^0C for 60 minutes. Thereafter, the crucible was withdrawn and cooled, then weighed to the nearest 0.001g. PMC was calculated using the equation (ASTM D1348-94, 2008):

$$PMC(drybasis) = \frac{(D)}{(E)} \times 100 \qquad (2.2)$$

Where; D = the change in oven dry weight of sample, in grams (g)

E = Original weight of sawdust, in grams (g)

2.3.3 PERCENTAGE ASH CONTENT (PAC)

To determine the PAC of the sawdust sample, a porcelain crucible was oven-dried and weighed until its weight was constant. 2g of sample was measured into a crucible and ashed at 550 ± 5^0C for a period of 4 hrs in the muffle furnace. The crucible was removed and cooled. After cooling, the ash content in the crucible was weighed to the nearest 0.001g. Ash content reflects the purity of the carbon.

PAC was determined using the following formula:

$$PAC = \frac{(C)}{(A)} \times 100 \qquad (2.3)$$

Where;

A = the weight of the sample, as received (g)

C = the weight of ash, in grams (g)

2.3.4 PERCENTAGE FIXED CARBON (PFC)

The percentage fixed carbon, PFC was determined using:

$$PFC = 100 - (PVM + PMC + PAC) \qquad (2.4)$$

2.3.5 HEATING OR CALORIFIC VALUE (HV)

The heating or calorific value of the sample was calculated using the equation (Bailey et al, 1982);

$$Hv = 2.326\ (147.6x + 144y)\ MJ/Kg \qquad (2.5)$$

Where x = the percentage fixed carbon

y = the percentage volatile matter

2.3.6 BULK DENSITY

The bulk density of the sample was determined using this formula: (Araki and Terazawa, 2004).

i.e Bulk density (gcm^{-3}) = $\frac{(W_b - W_a)}{V_o}$ (2.6)

Where; W_b = Combined weight of sawdust And volumetric cylinder

W_a = Weight of empty volumetric cylinder

V_o = Volume of sawdust (= 100cm^3)

2.3.7 POROSITY

The porosity was determined by measuring sawdust sample with apparent volume of 20 cm ^{3} mark in a volumetric cylinder and water carefully poured into it until the surface of water reached the marked line at 20 cm ^{3} level. Then, the combined weight of volumetric cylinder, sawdust and poured water was taken as W_{comb} while the weight of the sawdust particles, W_s and the weight of the empty volumetric cylinder, W_{vs} were also noted (Rizki et al, 2010). The porosity was then obtained using the formula; Porosity (%) = (2.7)

Where;

V_a = Volume of poured water (cm^3) plus the water in the sawdust

V_o = Volume of sawdust (= 20cm^3)

V_a (cm^3) = $W_{comb} - W_s - W_{vs}$ (2.8)

W_{comb} = the combined weight (grams) of volumetric cylinder, sawdust particle and poured water (grams)

W_s = the weight (grams) of sawdust particles (Oven-dry weight equivalent)

W_{vs} = the weight of volumetric cylinder (grams)

2.4 SAMPLE PREPARATION, CELLULOSE EXTRACTION AND CONFIRMATORY COLOUR TEST

2.4.1 CELLULOSE EXTRACTION

The cellulose was extracted using BABAB standard procedure as reported by Nemec et al (2010). The wood sample (1g) was first washed in 5ml of 4% NaOH, overnight in a beaker, the solution was then removed and the soaked sample treated with 10ml of distilled water and 5ml of 4% HCL for 1hr. Again, the sample was separated from the acid-water solution and sample washed in 4% NaOH for 1hr 30min and thereafter removed and treated with 5ml of 4% HCL for further 1hr. The solution was removed and the residual sawdust sample was contacted with 5ml of 10% $NaCl0_2$, 5ml of water and 2 drops of 4%HCL for 2hrs.

After bleaching for 2hrs, the beaker was placed in an ultrasonic bath for 15mins at 25^{0}C and a sharp yellow suspension was formed as a result of $C10_2$ and it was filtered off and the wood residue was washed with distilled water until the PH level was less than 4. The final product was turned into a crucible and dried in a muffle furnace.

The percent weight of cellulose = (W_{CC} – W_C) x 100

Where W_{CC} = the combined weight of crucible and extracted cellulose, in grams (g), W_C = the weight of the crucible in grams (g)

2.4.2 HEMICELLULOSE EXTRACTION

Hemicellulose content of the sawdust sample was extracted by Viscose method using the following experimental procedure as described by Mojmir (2010);

One gram (1g) of wood sawdust sample was soaked in 5ml of 17%NaOH overnight in a test tube. The soaked sample was then placed in a centrifuge set at 4000 RPM and the solution was separated from the soaked sample after 3 minutes centrifugation. The sample was again treated with the same quantity of NaOH for 1hr 45mins. This step was also repeated for another 1hr with the test tube positioned in water bath at 75^{0}C. The solution was removed after another 3mins of centrifugation and the soaked sample was treated with 2ml of CS_2 for 15mins in warm water bath. 3ml of 4% NaOH was added to the sample in the test tube and then intensely vortexed so as to form emulsion. Emulsification was done severally while the sample was kept in water bath for 3hrs.

2.4.3 EXTRACTION OF LIGNIN

The lignin content of the wood sample was extracted using the standard procedure as described by ASTM D1106-96 (2007).

The weight percent of Lignin was deduced using the formula:

Percent Weight of Lignin = ($W_{CL} - W_C$)

Where; W_{CL} = the weight of crucible and lignin content (g)

W_C = the weight of the crucible (g)

2.5 CONFIRMATORY COLOUR TEST FOR CELLULOSE

A triodide-phosphoric acid stain test is a confirmatory color test that was used to confirm the presence of cellulose in a wood sample. The mixture was prepared from an aqueous triodide solution, comprises of 0.6M potassium iodide (KI) and 0.1M iodine (I_2), the resultant KI_3 solution was mixed with 77% conc. phosphoric acid (prepared from 77ml of H_3PO_4 + 23ml of H_2O) in ratio 1 to 100 V/V of triodide to acid. The resultant solution was used to stain the extracted sample from the sawdust and appearance of blue colour indicates the presence of cellulose (Kimberly Clark, 1989)

3. RESULTS AND DISCUSSION

Table 3.1: Results of the proximate analysis for Ghana Obeche (*Triplochiton scleroxylon*) softwood sawdust

Component	% Weight (As received basis)
Moisture content	11.28 ± 0.33
Volatile matter	80.04 ± 1.13
Ash content	0.38 ± 0.14
Fixed carbon	8.30
Porosity	84.77 ± 0.253
Density	0.124 ± 0.002g/cm^3
Heating value	29.65 MJ/kg

The results of the proximate analysis of Ghana Obeche (*Triplochiton scleroxylon*) softwood sawdust are presented in Table 3.1. The experimental findings showed that the sample has a volatile matter, ash content, fixed carbon, heating or calorific value of 80.04%wt, 0.38%wt, 8.30%wt and 29.65 MJ/kg respectively.

Similarly, the results revealed that the moisture content, porosity and density of the biomass

sample are 11.28%wt, 84.77% and 0.124gcm^{-3} respectively.

The proximate analysis is important in determining whether the biomass sample is combustible or not (Mckentry, 2002). The importance of volatile matter as a proximate property in fuel combustion is that, it helps to know the extent to which the fuel can be ignited and subsequently gasified (Clarke and Petro, 2011).

And from the high value obtained for the volatile matter of the investigated Ghana Obeche softwood sawdust which is 80.04 %wt, it can be assumed that the sawdust sample will be a good source of wood fuel because it will produce the type of flame suggested by Clarke and Petro (2011). By comparison, this value is similar to those of wood samples like *C. Pentandra, P. Africana and A. robusta* examined by Mitchual et al, (2013) which have volatile matters of 82.43%wt, 80.60%wt and 75.23%wt respectively and were adjudged to be good source of fuel according to Austria and Germany standards for fuel performance measurement. So, this is an indication that the studied sample is very suitable for wood fuel production. Also, the low value of the ash content of the *Triplochiton scleroxylon* sawdust sample which is 0.38%wt makes it a good source of energy. A biomass sample with high ash content is not suitable as fuel during combustion. Shao et al, (2012) opined that a biomass that contains high ash content can be corrosive and more severe than that of bituminous coal.

The low ash content also indicates that the investigated sample would be a good source of fuel for the boilers. (Miller and Tillman, 2008).

Similarly, the sample has a fixed carbon content of 8.30%wt and Heating value of 29.65MJ/kg. The significance of these values is that the investigated sample is a good source of energy. This is because, apart from volatile matter, the other sources of ignition or gasification of fuel during combustion process is the heating or calorific value and organic carbon content.

According to Akowuah et al, (2012), fixed carbon provides a rough analysis of the heating value of a fuel and acts as the main heat provider during burning.

The heating value of the studied sample is another proximate property that makes it a good and efficient source of alternative fuel because it provides a basis for the standard measurement of the energy content of a fuel. The high heating value of 29.65MJ/kg compared to that of pine sawdust which is 15.10MJ/kg and 20.33MJ/kg, 22.17MJ/kg, 28.61MJ/kg for C. Pentandra, P. Africana and wood sawdust mixture sawdust samples respectively makes it more efficient than the other samples in comparison. Even though the studied sawdust sample comparatively has a lower heating value than that of fossil fuels like kerosene (46.5MJ/kg) and Natural gas (37.3MJ/kg), it is far above the DIN 51731 minimum requirement of 17.50 MJ/kg heating value before a material can be regarded as possessing adequate calorific or heating value. The heating value of this studied biomass is in line with that observed as a better performing briquette with the heating value of 33.09MJ/kg (Sotannde et al, 2010).

The values obtained for the density, porosity and the moisture content during the proximate analysis on the studied experimental sample are adequate for it to be regarded as good fuel source. The moisture content of 11.28%wt is within the range of the predicted moisture content of 5-20% dry basis of wood to be used for fuel. Comparing this value, i.e. 11.28%wt to that of pine sawdust and Afzelia Africana which are 16.44%wt and 11.5%wt (Wilson, 2010); it is the least in terms of water content because percentage moisture content is the decimal fraction of fuel that consists of water.

Moisture content has big effect on the calorific or heating value during combustion process because of the high energy requirement by vapourizing water during the burning process. Therefore, the low moisture content of studied *Triplochiton scleroxylon* sample makes it a good feed stock for alternative fuel because high moisture content reduces the heating value of the biomass.

Also listed in table 3.1 are the density and porosity of the *Triplochiton scleroxylon* sawdust sample. The

results reveal that density and porosity are 0.124 gcm $^{-3}$ and 84.77% respectively. The density of a biomass sample significantly affects its fuel value.

The high value of the porosity of the studied sample is 84.77% and provides a good basis for the sample to be considered as a good biomass material for production of wood fuel. Because it is a measure of void within the sample and it makes it easier to pulverize compared to samples with lower porosity.

3.2 ANALYSIS OF WOOD SAWDUST MAJOR CONSTITUENTS: Cellulose, Hemicellulose, Lignin and Extractives.

Table 3.2: Constituents of Ghana Obeche Softwood Sawdust

Component	(%wt.)
Cellulose	32.3
Hemicellulose	13.2
Lignin	20.5
Water S. Extractive	2.045
Ethanol S. Extractive	0.918

Table 3.2 shows the results of the major constituents and extractives of the studied Ghana Obeche softwood sawdust. The result shows that the yields of cellulose, Hemicellulose and Lignin are 32.3 wt.%, 13.2 wt.% and 20.5 wt.% respectively while water and ethanol soluble extractives are 2.045 wt.% and 0.918 wt.% respectively.

32.3 wt.% represents the quantity of cellulose sample extracted from 1g raw Ghana Obeche softwood sawdust sample. The cellulose is the final product of the base-acid-base-acid-bleaching method (Anchukaitis et al, 2008) as described in Nemec et al (2010) for cellulose extraction standard. It is a white porous and chalk-like material; its texture looks similar to the raw wood powder.

The yield of cellulose obtained from the studied sample is similar to that of tree core 30 wt.% using the BABAB extraction procedure. According to Anchukaitis et al, (2008), the yield of the cellulose extracted from wood biomass is mainly influenced by wood type, its preservation and the efficiency of the separation step where losses may occur during decantation after bleaching.

Similarly, the hemicellulose and lignin yields of *Triplochiton scleroxylon* softwood sawdust are 13.2 wt.% and 20.5 wt.% respectively. They are the other major constituents of lignocellulosic biomass and they also play important role during the production of bio-oil because they produce significant quantities of residual char and gas (Shen et al, 2010).

Also, the water soluble and ethanol soluble extractives of the studied sample are 2.045 %wt. and 0.918 %wt. respectively.

Extractives from the sawdust sample include fats, proteins, resins, sugars, gums, waxes, glucosides and so on (Mohan et al, 2006). Extractives play important roles in the formation of woody biomass; they function as energy reserves, protect the wood against insect attack and microbial destruction and consequently contribute to high yield of lignocellulosic properties of the wood. They also

contribute to properties like colour, flammability and decay resistance. Baker (1998) noted that, softwoods have more lignin than the hardwoods, and this is responsible for the slightly higher heating or calorific value of the softwoods.

3.3 Confirmatory colour test for cellulose

Figure 3.1: Effect of Triodide – Phosphoric acid stain test on cellulose after 1 minute

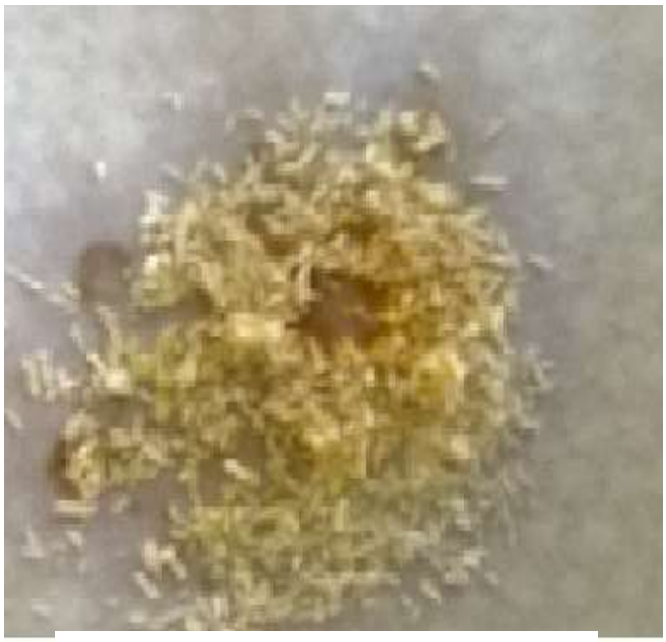

Figure 3.2: Effect of Triodide – Phosphoric acid stain test on cellulose after 5 minutes

Figure 3.3: Effect of Triodide – Phosphoric acid stain test on cellulose after 30 minutes

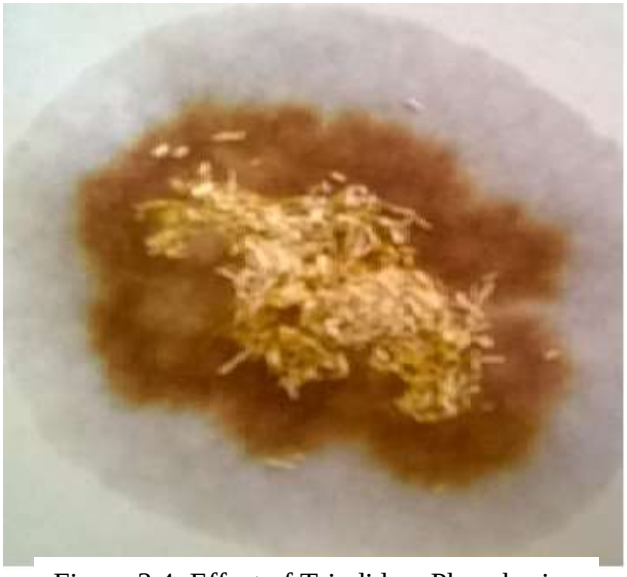

Figure 3.4: Effect of Triodide – Phosphoric acid stain test on cellulose after 1 hour

Figures 3.1, 3.2, 3.3 and 3.4 show the effect of the Triodide – phosphoric acid stain test on cellulose sample after 1 minute, 5 minutes, 30 minutes and 1 hour respectively. The stain test was performed to confirm the presence of cellulose in the extracted sample. The mixture was then used to stain the sample and appearance of blue colour confirmed the presence of cellulose.

4. CONCLUSION

The conversion and utilization of wood sawdust as biofuel has huge potential to provide alternative source of energy due to the current global energy crisis. This study investigated major chemical constituents of Ghana Obeche softwood sawdust in order to assess the viability of the chemical composition of the studied lignocellulosic biomass. The following conclusions were drawn after the experiment;

The results of the major chemical constituents and extractives indicate that the yields from the studied sample are good enough and meet the required standards and can compete favorably with other biomass materials and is therefore fit to be utilized as feed stock for bio-oil production.

The research outcome also showed that, the use of sawdust as a feedstock in biofuel production will go a long way in controlling environmental pollution that could be associated with indiscriminate burning of the sawdust and other agricultural wastes.

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