

Characterization Of Water Hyacinth (*Eichhornia Crassipes*) For The Production Of Thermochemical Fuels

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Abstract—The specific thermo-chemical conversion technology suitable for a given biomass depends substantially on its characteristics. Water hyacinth was characterized to determine suitable thermochemical conversion route to bio-fuels. The study revealed that pyrolysis and gasification routes to bio-oil and bio-gas respectively, is preferred to that of the bio-char. Thermogravimetric analysis indicates that the operational envelopes for pyrolysis and gasification reactions are 250 – 550 °C and 550 – 920 °C respectively.

Keywords—water hyacinth; characterization; thermochemical conversion; operational envelopes; bio-fuels

1. Introduction- Biomass is a carbon dioxide neutral renewable, low-sulphur energy source. Biomass energy will become one of the most useful energy sources of the future, especially in the tropical countries (Bridgwater, 1999; Bridgwater and Peacocke, 2000; Mohapatra and Gadgil, 2013). In view of these, much attention has been focused recently on identifying suitable biomass species, which can provide high-energy outputs (McKendry, 2002).

Water hyacinth (*Eichhornia crassipes*) is a green flowering, floating, fresh water plant native to South America. It grows and clogs inland waterways in warm climates so much that it is now considered as the worst aquatic weed in the world (Villamagna and Murphy, 2010; Zhang *et al.*, 2010).

Water hyacinth has an average annual productivity of 50 dry (ash-free) tonnes per hectare per year, is considered as one of the most productive plants in the world (Dhal *et al.*, 2011). The specific thermo-chemical conversion technology suitable for a given biomass depends largely on its characteristics (Gebrewold, 2010; Antony *et al.*, 2011). Therefore, there is the need to evaluate the properties of water hyacinth to know the suitability of the biomass in a given technology and the required process condition and emissions expected. Biomass is characterized by proximate analysis and ultimate analysis. Proximate analysis of biomass determines its moisture content, volatile matter, ash and fixed carbon; while ultimate analysis determines compositions of carbon, hydrogen, nitrogen, sulphur, oxygen and higher

heating value. Characterization can also be based on organic constituents as, cellulose, hemicelluloses, lignin and extractives. Composition is a function of biomass type (Lynd *et al.*, 1999).

Some researches have been reported on the pyrolysis, gasification and combustion of water hyacinth to produce bio-fuels (Hu *et al.*, 2015; Jiu *et al.*, 2015; Biswas *et al.*, 2017). But, no detailed studies were found by us in literature on the most suitable thermochemical route for the production of bio-fuels. Hence, the work investigates suitable thermochemical route or routes for the production of bio-fuels from water hyacinth.

2. Materials and methods

2.1 Collection of water hyacinth samples

Water hyacinth was harvested from the shores of River Nun at Tombia-Ekpetiama, Bayelsa State, Nigeria (Latitude 05° 00' 02.483" mN and Longitude 06° 15' 47.776" mE). The samples were thoroughly washed with clean water. The samples of water hyacinth were separated into leaves, stalks and roots. The roots were disposed off.

2.2 Sample preparation

The samples of water hyacinth were dried in an oven (PRECISION, Model 6525) at 105 °C for 24 hours to a constant weight, and were stored or collected in a desiccator until needed.

2.3 Water hyacinth sample analysis

The dry biomass samples were characterized for proximate analysis, component analysis and ultimate analysis, the most important characterization in biomass thermochemical conversion (Jones, 2011; van de Weerdhof, 2010) as follows:

2.3.1 Proximate analysis

Proximate analysis estimates the % of volatile matter, ash and fixed carbon content in a biomass sample. The procedure to estimate each of these quantities is based on ASTM methods in line with literatures (Marquez-Montesino *et al.*, 2015; Seal, 2013) as follows:

2.3.1.1 Determination of volatile matter

One gram of sample, free of moisture was placed in a crucible. The crucible with the sample was placed

in a muffle furnace at a temperature of 950 °C for seven minutes and then cooled in desiccators. The percentage of weight loss gave the volatile matter content, calculated as:

$$\% VM = \text{loss due to removal of volatile matter} \left(\frac{100}{\text{wt. of sample taken}} \right) \quad (1)$$

Where VM = volatile matter

Three replicates were obtained and the results averaged.

2.3.1.2 Determination of ash content

Five grams of the dry sample were placed in a crucible. The crucible with the sample was transferred into a muffle furnace at 600 °C for three hours. The percentage of weight loss gave the ash content. The ash content was calculated using equation (2):

$$\% \text{ of ash} = \text{weight of ash left} \left(\frac{100}{\text{wt. of sample taken}} \right) \quad (2)$$

Three replicate analysis were done and the results averaged

2.3.1.3 Determination of fixed carbon

The fixed carbon was calculated from the expression:

$$\% \text{ of fixed carbon} = 100 - \% \text{ of (moisture + volatile + ash) content} \quad (3)$$

2.3.2 Component analysis

The amounts of extractives, hemicellulose, cellulose, and lignin in water hyacinth samples were determined according to the following methods (Yang *et al.*, 2006; Walford, 2008; Marquez-Montesino *et al.*, 2015):

2.3.2.1 Determination of extractives in the biomass

Solvent extraction was used to determine the amount of extractives in the biomass. 60 mL acetone was added to 1 g of the dry biomass sample, and the temperature was held at 90 °C for 2 hours. After that, the sample was dried in an oven (105 - 110 °C) until a constant weight was obtained. The weight difference before and after the extraction is the amount of the extractives. Three replicates were obtained and the results averaged.

2.3.2.2 Determination of hemicellulose in the biomass

To determine the amount of hemicellulose, 150 mL of sodium hydroxide (NaOH) solution (0.5 mol/L) was added to 1 g of extractive-free dried biomass, and the temperature was held at 80 °C for 3.5 hours. After that, the sample was washed using deionized (DI) water until no more Na^+ was detected (indicated by the pH value of the solution approaching 7), and then

it was dried to a constant weight. The difference between the sample weight before and after this treatment is the hemicellulose content. Three replicate analysis were conducted and the results averaged

2.3.2.3 Determination of lignin in the biomass

Lignin was determined based on its insolubility in 98 % H_2SO_4 . To determine the amount of lignin, 30 mL of 98 % sulphuric acid was added for each gram sample (extractive-free dried biomass). After the sample was held at ambient temperature of 25 °C for 24 h, it was boiled at 100 °C under reflux for 1 h. The mixture was filtered, and then the residue was washed until the sulphate ion in the filtrate was undetectable (via titration of a 10 % barium chloride solution); it was then dried to a constant weight. The weight of the residue is recorded as the lignin content. Three replicate analyses was carried out and the results averaged.

2.3.2.4 Determination of cellulose in the biomass

Finally, the content of cellulose was determined based on the insolubility of cellulose in monoethanolamine. 150 mL of monoethanolamine solution was added to 1 g of extractive-free dried biomass and held at ambient temperature of 25 °C for 1 h, the mixture was filtered, lignin and hemicellulose dissolves, and then the residue dried to a constant weight. The weight of the residue is recorded as the cellulose content. Three replicates were obtained and the results averaged.

2.3.3 Ultimate Analysis and Calorific Value of Water Hyacinth Biomass

The ultimate analysis was used to identify the proportions of carbon (C), hydrogen (H), nitrogen (N), and oxygen (O) elements found in the water hyacinth. Perkin - Elmer Model 2400 Series II CHN/S elemental analyzer was used. The instrument determines the concentration of these elements by analysis of the different combustion products.

And the higher heating value was calculated using equation as (Greenhalf *et al.*, 2013):

$$HHV[\text{MJ/kg}] = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211ash \quad (4)$$

2.3.4 Thermogravimetric analysis of water hyacinth

The thermal degradation behavior of the dried water hyacinth sample was investigated using a Perkin Elmer Thermal Analyzer (STA 6000) under a nitrogen environment. Sample weights of 6 - 8 mg were used. The water hyacinth sample was heated with nitrogen gas flow rate of 19.7 mL/min to maintain inert atmosphere for the thermal degradation. The temperature range for the pyrolysis investigation was 30 to 950 °C with a heating rate of 30 °C/min. The average dried biomass particle size of 0.3 mm was used.

3. Results and discussion

3.1 Characterization of water hyacinth biomass

3.1.1 Proximate analysis

The results of proximate analysis carried out on the water hyacinth samples are presented in Figure 1. The volatile matter is mainly derived from the cellulose and Hemicellulose which is likely to be converted to biofuels in pyrolysis (Asadullah *et al.*, 2007; Jahirul *et al.*, 2012), was found to be 71.27 wt %. An indication that water hyacinth is suitable for the production of pyrolytic bio-oil. Fixed carbon which is obtained solely from the lignin component of biomass material are converted to bio-char and other carbonaceous materials in thermochemical conversion processes (Asadullah *et al.*, 2007; Jahirul *et al.*, 2012) was found to be 14.56 wt %

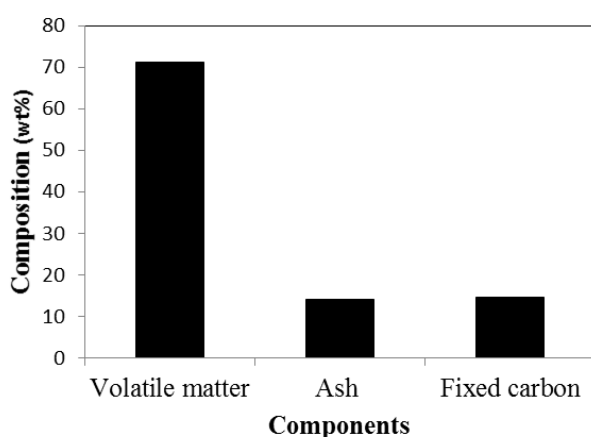


Figure 1: Proximate Analysis of Water Hyacinth (dry basis wt %)

The Ash content which is the residue after the combustion of the volatile matter content of the biomass material (Asadullah *et al.*, 2007; Jahirul *et al.*, 2012) was obtained as 14.56 wt %. Values of the proximate analysis compared favourably with previous works reported in literature of 70.35, 15.35 and 14.33 wt % for volatile matter, ash and fixed carbon respectively (Hu *et al.*, 2015).

The high volatile matter of the biomass envisages that it will readily de-volatilized when subjected to thermochemical reactions; liberating less fixed carbon, hence makes them more useful for pyrolysis and gasification. Ash content negatively affects the heating value. The ash content in the biomass is an integral part of plant structure which consists of a wide range of mineral matter such as salts of calcium, potassium, silica and magnesium (Asadullah *et al.*, 2007; Jahirul *et al.*, 2012).

3.1.2 Component analysis of water hyacinth

The results of the chemical composition analysis of water hyacinth are as presented in Figure 2. Results show that cellulose, hemicellulose and lignin are the major components of the aquatic plant. Hemicellulose has the highest composition of 27.90 wt %, followed

by cellulose at 26.50 wt %. Lignin concentration is 6.10 wt %, the least. The results are comparable to what was obtained in previous studies, which had cellulose (18.20 – 26.10 wt %), hemicellulose (26.80 – 48.70 wt %), lignin (3.50 – 6.30 wt %) and extractives (13.30 – 18.00 wt %) (Nigan, 2002; Luo *et al.*, 2011).

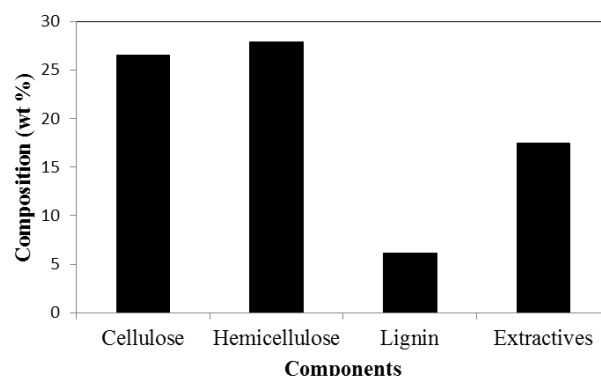


Figure 2: Component analysis of water hyacinth (dry basis wt %)

In a pyrolysis process, hemicellulose would be the easiest one to be pyrolyzed, next would be cellulose, while lignin would be the most difficult one. Bio-oil and bio-gas is mainly derived from the cellulose and hemicellulose component of biomass, whereas the solid residue (bio-char) came from the lignin (Asadullah *et al.*, 2007; Jahirul *et al.*, 2012; Fukuda, 2015). Therefore, water hyacinth has high potentials to produce bio-oil due to its high percentages of cellulose and hemicellulose. In contrast, water hyacinth may not be suitable for bio-char production as per low percentage of lignin.

3.1.3 Ultimate analysis of water hyacinth and calorific value

The elemental composition of water hyacinth biomass is given in Figure 3. It also has important effect on thermochemical product distribution. The low nitrogen content of 2.55 wt % favours bio-oil and bio-gas production (Friedl *et al.*, 2005).

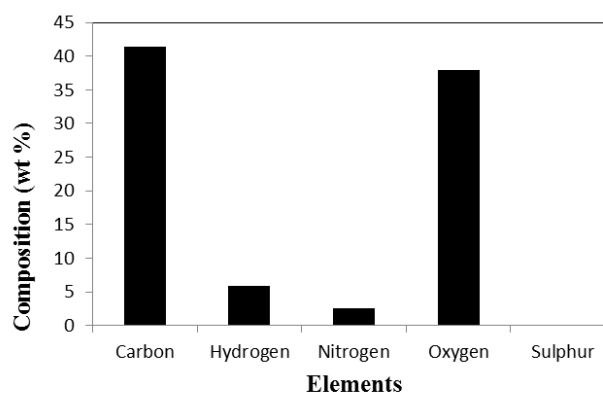


Figure 3: Ultimate analysis of water hyacinth biomass (dry basis wt %)

As can be seen from the Figure 3, the summation of carbon (41.47 wt %) and hydrogen (5.825 wt %) is

high, this results in high calorific value in water hyacinth biomass (Chaiya and Reubroycharoen, 2013); which was determined as 17.39 MJ/kg. The high calorific value envisages that it could be directly combusted for energy production. Also, the biomass contains negligible amount of sulfur which is a poisonous fuel component, hence, it can be considered as a suitable feed stock for pyrolysis to bio-oil and gasification to bio-gas (Asadullah *et al.*, 2007).

Previous studies reported C (33.00 – 46.52), H (5.30 – 6.61), N (1.5 – 4.3), O (27.5 – 39.70) and S (0.35 – 0.59) for water hyacinth (Bergier *et al.*, 2012; Hu *et al.*, 2015); which compares closely with the results obtained from the current study. The differences can be adduced to difference in geographical location of the biomass used in the different studies (Asadullah *et al.*, 2007).

3.2 Thermogravimetric analysis

Figure 4 is the TG profile showing the thermal decomposition characteristics of water hyacinth at a heating rate of 30 °C/min. The profile indicates that most of the loss in weight occurs in the temperature range of about 250 to 550 °C. This establishes the temperature range for the pyrolysis reactions. It is also evident from the contours in the figure that the pyrolysis

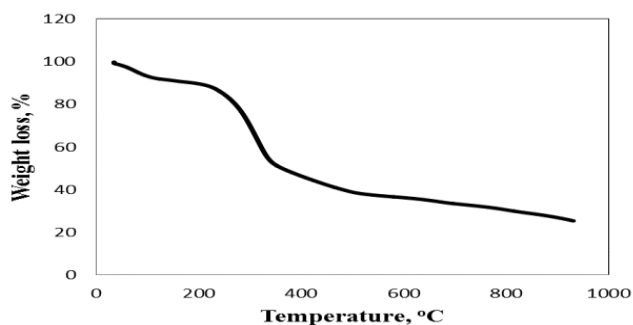


Figure 4: TGA profile of water hyacinth under nitrogen atmosphere

reaction of water hyacinth involves three lumped consecutive reactions: vaporization, devolatilization and secondary cracking reactions in harmony with literatures (van de Weerdhof, 2010; Jones, 2011).

The first weight loss is attributed to the removal of moisture and light volatiles in the biomass which is followed by the decomposition of volatile matter and removal of volatiles (i.e. devolatilization) at about 250 to 550 °C, indicated by a sharp endotherm in the TGA. Most of the weight loss takes place in this phase. Devolatilization is followed by secondary cracking reactions. Degradation of hemicellulose takes place at (220 - 315 °C); and cellulose decomposition (315 - 400 °C) and lignin degradation (>450 °C). The loss of lignin typically occurs at a slower rate over a much wide temperature range of 180 - 900 °C (El-Sayed and Mostafa, 2014). Water hyacinth biomass comprises of hemicelluloses, cellulose and lignin as the major components and the devolatilization region

correspond mainly to the degradation of these components. Devolatilization reactions lead to the formation of the pyrolysis products of tar or bio-oil, non condensable gases and char.

The third region sees a much lower rate of weight loss than the second stage, which is secondary reactions; the degradation of heavier volatiles (or tar), the cracking of C-C bonds and the formation of char decomposes the tar to gas, therefore, it is desirable to minimize secondary reactions in the design of pyrolysis system for the maximization of bio-oil production (Swart *et al.*, 2012). The decomposition of lignin has also been reported to continue into this region (El-Sayed and Mostafa, 2014). Gasification reactions take place in this region of 550 – 920 °C.

4.0 Conclusion

The following conclusions could be drawn from this study:

- Water hyacinth could be more suitable for pyrolysis and gasification reactions to produce bio-oil and bio-gas respectively, than bio-char production.
- Water hyacinth could be directly combusted to heat energy considering is high higher heating value of 17.39 MJ/kg.
- The operational envelope for pyrolysis reactions to produce bio-oil lies between 250 - 550 °C.
- 550 – 920 °C is the operational envelope of gasification reactions to produce bio-gas.

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