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Research paper

Chemical and energetic characterization of eucalyptus chips as a small-scale biomass power plant at mai-chew particle board factory site

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Abstract

Biomass has emerged as a renewable energy source with a high potential to contribute to the energy needs of both developed and developing countries. This study was aimed at analyzing the Ultimate, proximate, and heating value of the white eucalyptus biomass waste was characterized and is high quality for bioenergy purposes. From the triplet experimental results of the on proximate analysis of the biomass were 81.711, 0.98, 3.099, and 14.21% for volatile content, ash content, moisture content, and volatile matter respectively. In addition, the ultimate analyses of the eucalyptus chips were 49.7, 6.08, 0.24, 43.913, and 0.067% for Carbone, hydrogen, nitrogen, oxygen, and sulfur content respectively. Finally, the lower heating value (LHV) and higher heating value (HHV) were 18,675.49 and 19,992.07283 KJ/Kg respectively.

Keywords: *Biomass; Eucalyptus Chips; Power Plant; Proximate Analysis; Ultimate Analysis.*

1. Introduction

To reduce the dependence on coal and fossil fuels, renewable energy sources such as hydropower, solar, wind, and biomass have been used as a supplementary energy source (Auler et al. 2020; Unchaisri et al. 2019). Forest biomass is an obvious candidate to replace renewable energy sources due to its carbon neutrality and potential for conversion into high-value-added products (Arteaga-Pérez et al. 2015). In addition, biomass energy sources lower NOx and SOx emissions (Unchaisri et al. 2019). Biomass; which is a non-fossilized and biodegradable organic material; can originate from plants, animals, and microorganisms (Auler et al. 2020). On average, biomass accounts for about 9–14% of the total energy supply in developed countries such as the United States, and in developing countries, it accounts for about one-fifth to one-third (Khan et al. 2009). Biomass is the fourth largest available primary energy source in some developing countries (Yuningsih et al. 2023).
Biomass is considered a fundamental energy source, especially in sub-Saharan countries such as Ethiopia. Ethiopia is suffering from significant depletion of domestic biomass resources. Therefore, developing appropriate institutions and technologies to produce renewable energy from biomass is extremely valuable (Diriba Guta 2012). The use of biomass power plant technology improves waste management, nutrient recycling, job creation, utilization of rural surplus agricultural land and modern energy sources, and has been recognized in countries that have legislated it (Abdelhady, Borello, and Shaban 2018). Nevertheless, there are still high hurdles to overcome for the successful development of sustainable biomass energy. These include the complex and expensive logistics as well as the political, ethical and ecological challenges of competing with agriculture (Arteaga-Pérez et al. 2015).

2. Materials and methodology

2.1. Data collection

In the experimental study, biomass was collected from the Mai-chew particleboard factory in the southern Tigray region of Ethiopia. The southern region of the Tigray region is ecologically rich and eucalyptus trees are abundant. The main data sources were questionnaires and site visits. Finally, the homogenized biomass waste samples were brought from the factory for characterization.

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2.2. Study area, sample collection and preparation

Homogenous white eucalyptus biomass waste was collected from the Mai-chew particleboard factory, southern Tigray, Ethiopia, located at a latitude and longitude of 12.7833 and 39.5333 respectively. The bold red color arrow in the Figure 1 indicates the location of the collected sample or factory site.

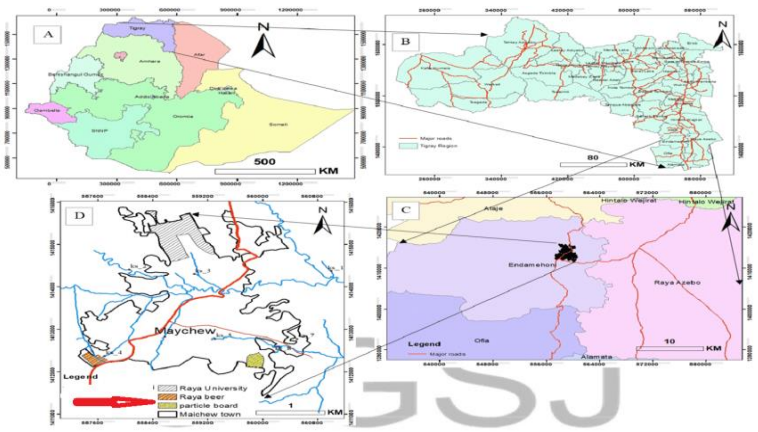


Fig. 1: Location Map of Study and Sample Collected Area (Estifanos, Hagos, and Abrha 2020).

The amount of feedstock collected was between 3 and 5 kg in weight. Visible sand, soil, and other contaminants were removed manually. The experimental data presented in this study were the average of three measurements. The general outline of the experimental methods which were given in Figure 2 and Figure 3 shows some of the target areas, in which the sample was collected.

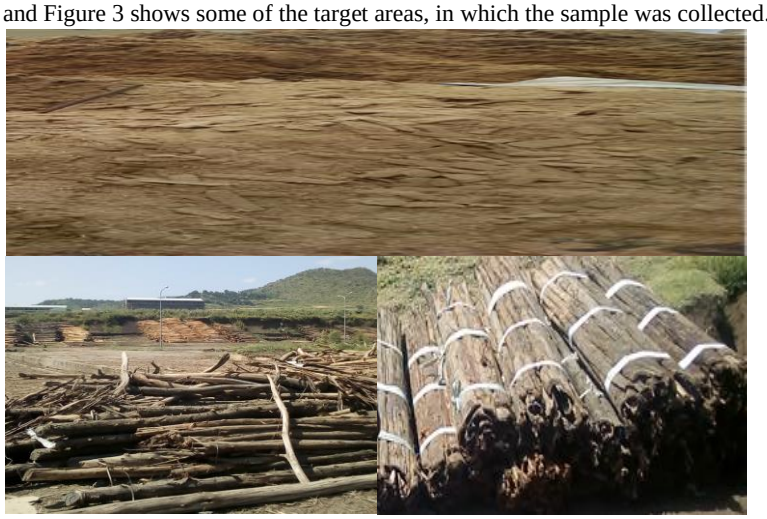


Fig. 2: Sample Collected Areas Near and in the Factory.

The raw materials were sun-dried for 24 hours under ambient atmospheric conditions, after which excessive sunlight and some moisture were avoided. The samples were ground into 3–5 mm particle size. After crushing, the biomass samples were sieved through a 1 mm diameter sieve and stored in a polyethylene bag to avoid moisture loss during transportation in the laboratory. Some of the sample preparation steps are shown in Figure 3.



Fig. 3: Sample Preparation.

The biomass waste which is the white eucalypts waste was examined physiochemically and characterized to understand their compositional and structural properties.

2.3. Characterization of white eucalypts biomass waste

2.3.1. Proximate analysis

The physical parameters of the powdered biomass samples were characterized using proximate analysis. Proximate analysis, which is a standardized procedure that gives an idea of the bulk components, that make up a fuel. It was carried out at the Hydro-Geochemistry Laboratory of Mekelle University and was used to determine the average of the percentage volatile matter content (VM), percentage ash content (ASH), moisture content (MC), and percentage content of fixed carbon (FC) of the biomass waste. ASTM standard procedures were adopted to obtain the following experimental procedure.

2.3.1.1. Moisture content

The moisture content of white eucalyptus biomass waste was measured in accordance with the standard for woody biomass and in accordance with ASTM standard (D-871-82) (E871-82 2014). First, the mass of the watch glass was weighed to 37.17 g according to the standard using an electronic balance (JINNUO-TD20002), and then 20 g of a white eucalyptus biomass waste sample was weighed. The samples were placed in an oven and dried at 105 °C for 30 min. The samples were then left at a temperature of 105 °C for 24 hours until they reached a constant weight. The weight loss was recorded to determine the moisture content of the woody sample. The fuel moisture content (MC) is determined based on the mass loss of the sample before its oxidation. Then, its value was calculated using equation (1). This analysis was performed in triplicate and the results were expressed on a dry weight basis.

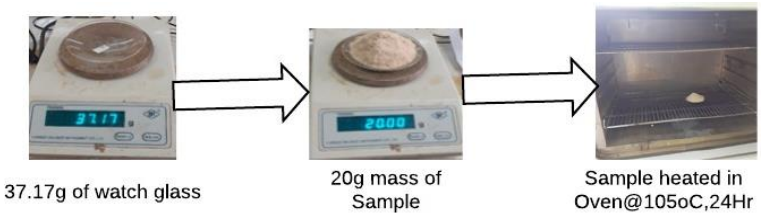


Fig. 4: Experimental Procedure of MC (%) Estimation.

Then the moisture was calculated as follows.

$$\text{Moisture content (MC)}\% = \frac{W_0 - W}{W_{s0}} * 100 \quad (1)$$

Where; W_0 represents the initial weight of the sample and watch glass together, W is the resulting dry weight of the watch glass plus dry sample and W_{s0} is the initial sample weight.

2.3.1.2. Volatile matter

The volatile matter of woody biomass fuel refers to condensable and non-condensable Vapor released when the fuel is heated. Volatile content was determined according to the ASTM E-872 standard (ASTM 2011). The mass of the crucible (30 mm < H < 35 mm) is initially 172.33 g. The sample is polished to a size less than 1 mm and 1g was taken, dried, and placed in a silica crucible (30 mm < H < 35 mm). The crucible was then placed in a muffle furnace model (Lenton Thermal Design EF11/8B) at 950 °C and is heated for 7 minutes. The volatiles released are detected by luminous flame. After 7 minutes, the crucible was removed and cooled in a desiccator (vacuum desiccator with silica gel). To prevent moisture absorption during cooling, the samples were stored in a desiccator until they reached ambient temperature before being weighed. To determine the weight loss, the weight was measured and the value was calculated using equation (2). All analyses were performed in triplet time and results were expressed on a dry weight basis.

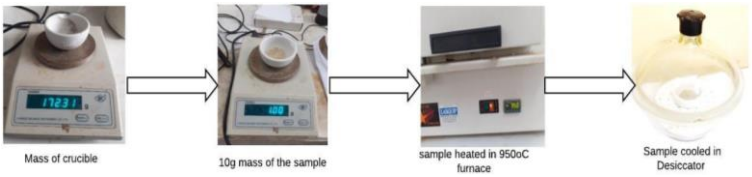


Fig. 5: Experimental Procedure of VM (%) Estimation.

$$\text{Volatile matter (VM}\%) = \left(\left(\frac{W_{v0} - W_v}{W_{s0}}\right) * 100\right) - \%\text{Moisture} \quad (2)$$

Where; W_{v0} represents the initial weight of the sample plus crucible with top, W_v is the resulting weight of the crucible plus top and sample waste and W_{s0} is the initial sample weight.

2.3.1.4. Ash content (AC)

The ash content of the white eucalyptus biomass waste was expressed by dry weight basis analysis. According to the ASTM D1102, (Ramalho and Bento 2006), the mass of the crucible (30 mm < H < 35 mm) was initially 172.23 g. 10 g of dried sample mass was placed in a crucible and placed in a muffle furnace model lent on thermal design (EF11/8B) at 600 °C for 4 h. The crucible containing the sample was then removed and cooled in a desiccator (CSN®SIMAX). The weights of the crucible and the sample were then recorded and the value was calculated using Equation (3). All analyses were performed in triplicate and results were expressed based on dry weight.

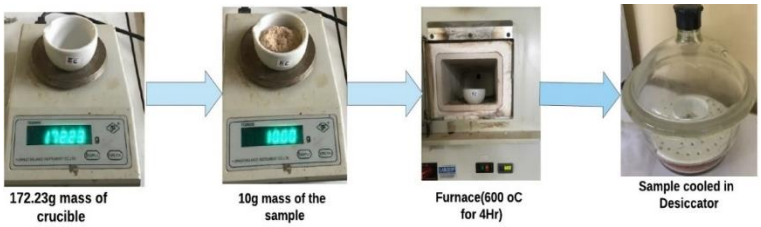


Fig. 6: Experimental Procedure of AC (%) Estimation.

The ash content (%) was calculated as;

$$\text{Ash Content (AC\%)} = \frac{(W_3 - W_1)}{(W_2 - W_1)} * 100 \quad (3)$$

Where; W_3 is the mass of the empty dry crucible, W_2 is the mass of the dry crucible plus the dry sample of biomass and W_3 is the mass of the dry crucible plus the cooled grayish-white ash.

2.3.1.4. Fixed carbon

A sample of white eucalyptus biomass consists of moisture, volatile matter, ash, and fixed carbon. As per the standard procedure, fixed carbon was estimated by subtracting the amount of the remaining three constituents from the initial amount of the sample. Fixed carbon can also be determined using an empirical formula by subtracting the experimentally determined sum of moisture, ash, and volatile content from 100 (% by mass) (Álvarez-Álvarez et al. 2018) as in equation (4):-

$$\%\,\text{FC} = 100 - (\%\,\text{VM} + \%\,\text{AC} + \%\text{MC}) \quad (4)$$

Where; FC is the fixed carbon, VM is the volatile matter, AC is ash content and MC is moisture content.

2.3.2. Determination of calorific /heating value and ultimate (elemental) analysis

Measurements of the calorific value of white eucalyptus biomass waste were carried out at the Messobo cement factory in Mekele, Tigray Region, Ethiopia. The instrument used for the determination was the Bomb Calorimeter. A portion of the sample was ground and passed through a 0.2 mm sieve, and approximately 0.5 g of the ground material was pressed into pellets and placed in an insulated oxygen cylinder according to the ASTM D2015 standard test method for measuring the higher heating value of combustion (HHV). The higher heating value was also estimated by using equation (5) (de Sales et al. 2017).

$$HHV = 349.(C) + 1178.3.(H) + 100.5.(S) - 103.4.(O) - 15.1(N) - 21.1\,.1(Ash) \quad (5)$$

Where; C, H, O, N, and S are the contents of carbon, hydrogen, sulfur, oxygen, and nitrogen as determined by the ultimate analysis on a dry basis. The lower heating value (LHV) was then calculated by subtracting the energy required to evaporate the moisture content of the fuel by using the proposed equation (6) (Gebreegziabher et al. 2014).

$$LHV = HHV - 9mH\,(h_{fg}) \quad (6)$$

Where mH is the mass fraction of hydrogen in the solid fuel and h_{fg} is the latent heat of vaporization of water (enthalpy of vaporization) taken as 2410 KJ/Kg (de Sales et al. 2017).

The ultimate analysis is often determined using standards developed for coal (BS 1016: Part 6, 1977; ASTM 03176-84, 1984). The elemental composition (carbon, nitrogen, hydrogen, sulfur) of the samples was determined using an EA 1112 Flash CHNS/O analyzer located in the laboratory of the Department of Chemistry, Addis Ababa University. Under Carrier gas flow rate of 120 ml/min, reference flow rate of 100ml/min, oxygen flow rate of 250 ml/min furnace temperature of 900^0C and oven temperature of 75^oC. Next, estimate the oxygen content (in percent) of the white eucalyptus biomass waste by subtracting the percent of other elements (C, N, H, and S) from the total using equation (7) (Fuels, 2013, Pedro et al., 2018).

$$O\,(\%) = (100 - C\,(\%) + H\,(\%) + N\,(\%) + S\,(\%)) \quad (7)$$

3. Results and discussion

3.1. Biomass characterization

Without considering the approximately 560 kg/hr. amount of biomass waste used for heating purposes; 5,754.656 tone/year of biomass waste is just pure waste. Its physical and chemical characteristics are considered of high quality for energy application, with the capacity for edaphoclimatic adaptation and high biomass productivity indexes (Sette et al. 2020).

3.1.1. Proximate analysis

The proximate analysis determines white eucalyptus biomass components in terms of fixed carbon content, volatile matter, ash content, and moisture content of the fuel. The result of the proximate analysis of the biomass is presented in Table 1. As shown in Table 1, an average volatile content of 81.711% was recorded and this result is all most similar to the result reported by Gominho et al and Nhuchhen & salam approximately 81% (Gominho et al. 2012; Nhuchhen and Abdul Salam 2012). The high volatile matter content shows that during

combustion and gasification, most of the feed will volatilize and burn as gas in combustion chambers (Guerrero et al. 2005). Again, as indicated in Table 1, the average ash content value of the white eucalyptus biomass waste of 0.98% was recorded and reported by Guerrero, which is 0.98% ash of the eucalyptus (Guerrero et al. 2005) in addition to that Nhuchhen & salam (Nhuchhen and Abdul Salam 2012) obtained a value of 0.76% and Ap et al (de Sales et al. 2017) reported value of 0.79%. A high ash-containing fuel, an efficient dust removal system becomes critical, to handle particulate emissions and lower the heating value of the fuel. The result of the moisture content of the biomass is presented in Table 1. The average value of the moisture content of the white eucalyptus biomass waste of 3.099% was recorded. Guerrero et al reported that the (Guerrero et al. 2005) moisture content of the eucalyptus tree is 7%, and Gominho recorded 3.8% moisture content of the stump of a eucalyptus tree in one of their sites, which is somehow related to the result of this thesis (Gominho et al. 2012). However, since the moisture content is a physical parameter of woody biomass it may be affected by the age of the tree, the climate condition of the area and other related factors. Therefore biomass shows the highly variable result of their moisture content (Viana et al. 2018).

Table 1: Proximate analysis of white Eucalyptus biomass waste summary result

	Property	unit	value	Method
Proximate analysis	Moisture content (MC)	Wt. % (air)	3.099	
	Ash content (AC)	Wt. % (dry)	0.98	
	Volatile matter (VM)	Wt. % (daf)	81.711	
	Fixed Carbone (FC)	Wt. % (daf)	14.21	Eq (4)

3.1.2. Ultimate analysis

The ultimate analysis determines the chemical composition of fuels in terms of carbon, hydrogen, oxygen, nitrogen, and Sulphur as mass percentages of dry and ash-free (daf) biomass material. Elemental analysis of the white eucalyptus biomass waste from CHNS analyzer (EA 1112 Flash CHNS/O- analyzer) under carrier gas flow rate of 120 ml/min, reference flow rate 100 ml/min, oxygen flow rate 250 ml/min; furnace temperature of 900 °C and oven temperature of 75 °C conditions were done in duplicated run at Addis Ababa University and the average values were taken as represented in Table 2. The amount of carbon and hydrogen content in the biomass is very satisfactory as they contribute immensely to the combustibility of any substance in which they are found. The low Sulphur and nitrogen contents in the biomasses have welcomed the development as there will be a minimal release of Sulphur and nitrogen oxides into the atmosphere and that is an indication that the burning of biomass is examined in this work will not pollute the environment. According to Hamza, Zandi & Tokimatsu conclusion knowledge of the chemical composition is significant in determining the combustion characteristics in the power plant (Hamzah et al.,2017).

The elemental contents of (C, H, O, N and S) listed in Table 2 that, white eucalyptus biomass waste contains a higher proportion of Carbone content compared with hydrogen and oxygen which increased the energy value. The lower concentration (percentage) of nitrogen and sulfur (which is 0.00134 in the flue gas at stochiometric air) in biomass fuels is especially important for environmental protection. Extensive work has been reported in the literature on the ultimate analysis of biomass eucalyptus approximately similar to the author of this research's result (Arias et al. 2008; Guerrero et al. 2005; de Sales et al. 2017).

Table 2: Ultimate analysis of white Eucalyptus biomass waste summary result

	Property	unit	value	Method
Ultimate analysis	Carbone (C) content	Wt% (daf)	49.7	
	Hydrogen (H) content	Wt% (daf)	6.08	
	Nitrogen (N) content	Wt% (daf)	0.24	
	Oxygen (O) content	Wt% (daf)	43.913	Eq. (7)
	Sulfur (S) content	Wt% (daf)	0.067	
	Total		100%	
Calorific value	Net calorific value (LHV)	KJ/Kg	18,675.49	Eq. (6)
	Gross calorific value (HHV)	KJ/Kg	19,992.07283	Bomb calorimeter

The estimated value of the higher heating value (HHV) by using equation (5) from the result of ultimate analysis which is 19950.52 (KJ/Kg) is almost close to the experimental value 19992.07283 (KJ/Kg) determined from Messobo cement factory by using a bomb calorimeter. Approximately similar results were reported by (Arias et al. 2008; Gominho et al. 2012; Guerrero et al. 2005; de Sales et al. 2017). Those literature have reported the result of a gross calorific value of approximately 19 MJ/Kg.

4. Conclusion

In recent years considerable attention has been paid to renewable energy sources for power generation from biomass. Knowledge of the chemical (ultimate) and physical (proximate) characteristics of biomass is significant in determining the combustion characteristics in the power plant. The physical and chemical characteristics of white eucalyptus biomass waste at the Mai-chew particle board factory are considered of high quality for bio-energy application due to high calorific values with a result of 18,675.49 KJ/Kg for LHV and 19,992.07283 KJ/Kg for HHV as well as lower sulfur content, which is 0.067%.

Authors' contributions

LTG, TGG, and FAB conceived the problem of the study, prepared research proposals and developed the overall design of the research; prepared the first draft of the manuscript as well as approved the manuscript for submission.

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Availability of data

The data sets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests

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