

COMBUSTION CHARACTERISTICS OF SELECTED TROPICAL WOOD RESIDUES IN RELATION TO PARTICLE SIZE

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Abstract

Evaluation of combustion properties of biomass wood species is becoming more needful to improve and enhance the development of their utilisation as energy fuels. The study evaluates the particle size effect on energy potentials of commercially available tropical wood residues - Teak (*Tectona grandis*, TG), Apa (*Afzelia africana*, AA) and Ara (*Albizia pedicellaris*, AP), collected from Ilorin, Nigeria. These tropical wood species were pulverised into different particle

sizes of less than 0.25 mm, 0.25 - 0.5 mm and 0.5 - 1.0 mm. The moisture content, volatile matter, ash content, fixed carbon, calorific (heating) value and elemental composition of these wood species samples for different particle sizes were evaluated in accordance to ASTM standards. The particle size of 0.5 - 1.0 mm presented the best quality within the considered particle sizes. Sample AA has the highest calorific value of 30.03 MJ/kg at particle size of 0.5 - 1.0 mm, while sample TG has lowest energy value at less than 0.25 mm with energy content of 8.84 MJ/kg. The results obtained revealed that particle size plays a significantly role in combustion properties of woody biomass residues as solid fuel.

Keyword: proximate, ultimate, biomass, combustion, heating value

1 Introduction

Sustainable, renewable and alternative energy options have recently dominated forum of scientists, engineers and stakeholders of many countries in the world today. Most especially at the present time of global energy crisis, climate change challenges and environmental degradation which had led to an intense quest for more sustainable and suitable environmental friendly energy supply to replace fossil fuels and their derivatives [1], [2]. Among the alternative energy sources, biomass is one of the most vastly available, contributing about 14% of the world energy consumption [3]. Woody biomass contains a lot of energy, for instance, the low heating value (LHV) of dry wood ranges between 4300 and 5400 kWh/t, depending on the species of the tree, soil type and the age of the tree [4], [5].

Generally, biomass can be classified as woody and non-woody biomass. Woody biomass comprises mainly of products and by-products derived from the forest, woodland and trees sector. Non-woody biomass includes agricultural crops, agro-forestry residue, herbaceous products, animal waste as well as tertiary waste [6]. It has been established over the years, that biofuel has the potential to compete favourably with fossil fuel as it is considered carbon neutral fuel when it is burnt. However, several issues related to the inherent properties of lignocelluloses biomass need intense studies and investigations to enhance their energy density and economic values.

Biomass residues have great potentials in most of African countries, since they can be used as alternative to raw firewood. However, only a small proportion of the residues have effectively been used because of its high moisture content, low energy density, high polymorphism and lack of adequate knowledge on their combustion properties [7], [8]. These impediments reduce the energy density of the biomass, increase bulk density thus increase handling, transportation and storage costs, reducing vital economic and social benefits consequently making the utilisation of biomass as energy fuel almost impracticable [9]. Efficient and economical conversion of woody biomass into a high value energy fuel and chemical derivatives are the topmost priorities for researchers, energy industries and policy makers to enhance the national energy endowments, in order to build an efficient energy framework to reduce over dependence on fossil fuels and create a more robust energy value chain [10].

Series of pre-treatment processes have been implored over the years to enhance the energy values in biomass in order to gain comparative advantages over the fossil fuel. Among these pre-treatment processes are pelletisation, torrefaction, anaerobic digestion, transesterification, pyrolysis, gasification, drying and fermentation [11], [12]. Before any of these processes, there is need to classify and characterise the raw woody biomass such that a wealth of knowledge on the

inherent property of particular species of biomass can be made available and correlation with their combustion properties needs to be established. This research focused on the examination of some selected biomass residues in their unprocessed forms while some fundamental energy analyses such as proximate and ultimate analyses were carried out on them in relation to their combustion characteristics.

2 Materials and methods

2.1 Materials

The tropical wood species selected for this study were sourced from Ilorin, North central Nigeria, based on the predominant market availability of the species. Teak (*Tectona grandis*, TG), Apa (*Afzelia africana*, AA) and Ara (*Albizia pedicellaris*, AP) were found to be very popular in the market, and their supplies are regular throughout the year with highest residues production during milling, constructions and felling. They are collected, stored and air-dried for about three months in the wood workshop, University of Ilorin, Nigeria.

2.2 Methods

2.2.1 Drying, milling and sieving

The samples were oven-dried according to ASTM standard D1762-84 procedure at a temperature of 105 °C for 2 h and afterwards crushed, milled and sieved into particles sizes of <0.25, 0.25 - 0.5 mm and 0.5 - 1.0 mm. The biomass samples were thereafter stored in desiccators at room temperature in Ziploc plastic bags for about four months after the drying.

2.2.2 Proximate analysis

The moisture (*M*) contents of the biomass samples were determined by using RADWAG USA PMC 50/1 moisture analyser. The ash content (*AC*) was determined using a muffle furnace in accordance with ASTM 3174-04 standard procedure. To determine the ash content, 2.0 g of biomass sample in a crucible was placed in a muffle furnace, maintained at 575 °C for 4 h. The crucible was thereafter removed from the furnace and placed in the desiccators to cool. These heating and cooling processes were repeated until constant weights were obtained. The volatile matter (*VM*) in the biomass was determined using ASTM D 3175-07 procedure. To determine the volatile matter, 2.0 g of biomass sample in a crucible was placed in a muffle furnace, maintained at 950°C for 7 min. Then, the crucible was removed from the furnace and placed in the desiccators to minimise moisture absorption. The loss of weight was evaluated to give the volatile matter in the biomass. All these procedures were repeated at least in triplicate to ensure consistency. The fixed carbon content (*FC*) was calculated using the balance, i.e. [13]:

$$FC\% = 100 - Ash\% - VM\% - M\% \quad (1)$$

Where *FC* (%), *Ash* (%), *VM* (%), and *M* (%) are the mean of the mass percentages for fixed carbon, ash, volatile matter and moisture of the raw sample respectively.

2.2.3 High heating value (HHV)

HHV of the biomass samples were prepared in triplicate for each sample, these were determined using a Parr oxygen bomb calorimeter model 1341 in accordance to the ASTM D5865-04 standard. Each raw biomass sample of 2.0 g was pelletised into 10 mm diameter shape in a Laboratory hydraulic press at a pressure of 13.8 MPa and dried prior to charging the bomb, and combusted under oxygen atmosphere and the temperature rise recorded at 1 min intervals to calculate the HHV for each sample. HHV value was determined using the relation:

$$HHV(kJ/kg) = \frac{(E\Delta T - \epsilon Gd)}{G} \quad (2)$$

Where E is the heat capacity of calorimeter (9080 kJ/kg), ΔT is the change in temperature of the sample

2.2.4 Ultimate analysis

The common organic elements such as C, H, O and N were obtained based on proximate analysis data using the following mathematical model [14]:

For carbon content:

$$C = 0.97 FC + 0.7 (VM - 0.1 AC) - MC (0.6 - 0.01 MC)\%, \quad (3)$$

For hydrogen content:

$$H = 0.036 FC + 0.086 (VM - 0.1 AC) - 0.0035 MC^2 (1 - 0.02 MC)\% \quad (4)$$

For nitrogen:

$$N = 2.10 - 0.020 VM\% \quad (5)$$

While the oxygen was determined by means of difference, i.e.:

$$O = 100 - \% (C + H + N + Ash) \quad (6)$$

2.2.5 Pellet preparation

ORIGO HP50 Hydraulic press was used in the pellets preparation. A die made of cylindrical cross-section with a known diameter and length made of hard steel was constructed such that it has a closed end using a removable backstop. Pressure is applied using a mild steel piston and a compression tester. The compression force was read from the scale attached. The die was properly cleaned after each use and when changing samples. Pellets were built in sequential layers which enabled the pelletizing process to be simulated within commercial pellet mill. Biomass were loaded step-wise in amount less than 0.25 g into the die and then compressed until a maximum loading force of 40,000 N was achieved. The pellets were removed from the die by removal of the backstop and pushed out by applying pressure on the pellet using the hydraulic press.

3 Results and discussion

This study presents an in-depth investigation on the combustion characteristics of some tropical wood residues in relation to their particle sizes. The tropical woody-biomasses of African origin

investigated are Teak (*Tectona grandis*) TG, Apa (*Azela africana*) AA and Ara (*Albizia pedicellaris*) AP. The basic fuel properties such as proximate, ultimate and calorific values were presented for the selected wood species for the particle sizes of < 0.25 mm, 0.25 - 0.5 mm and 0.5 - 1.0 mm respectively.

3.1 Moisture content

Figure 1 shows the variation of moisture content of the different biomass samples with particle size. Figure 1 shows that the smaller the particle size the lower the moisture content in the samples. This can be viewed from the structural arrangement of inter-molecular bond between the particles of the smaller grains, which provide room for the penetration of atmospheric air into the samples, allowing absorbed water molecules in the sample to dry up rapidly by surrounding dry air. This is shown in the samples AA and TG, which were measured under wet basis with the highest moisture contents of 8.39 wt.% and 8.23 wt.% respectively of particle size between 0.50 - 1.00 mm. The MC in the particle size less than 0.25 mm were found to be 7.77 wt.% and 6.15 wt.% w.b., showing that the smaller the grains, the lower the moisture content in the biomass samples. The moisture content has influence on the calorific value, temperature of combustion and combustion properties of the biomass because water molecules in the lignocellulosic composition of biomass have negative effects on the combustion reaction of the process.

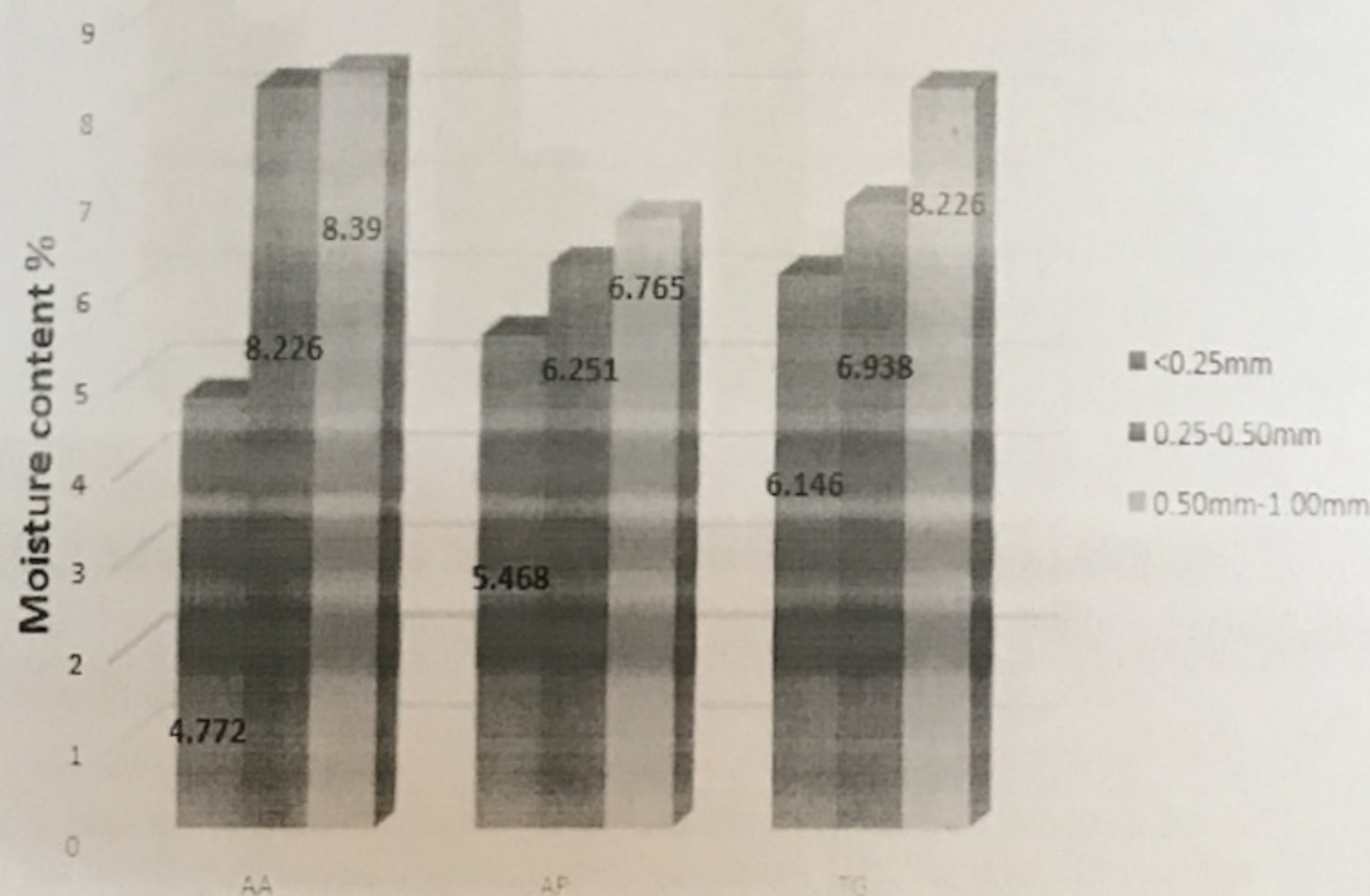


Figure 1: Variation of moisture content of the different biomass samples with particle size

3.2 Ash content

Figure 2 depicts the variation of ash content formation of different biomass samples with particle size. From the results obtained, the sample AA has its highest amount of AC in the particle size < 0.25 mm being 7.24 wt.%, while the lowest AC in the same AA, particle size between 0.50 - 1.00 mm as 2.4 wt.%. This can be explained from the point of view that combustion process, which one of its end products is ash is quickly formulated in the smaller grains compare to larger grains. The thermal degradation into ash for woody biomass of smaller particles size is faster than larger size [14]. During the combustion process of AP to form ash under the same conditions, it was observed that the particle size < 0.25 mm degraded into highest amount of ash with 5.84 wt.%, while the lowest AC was found in the particle sizes between 0.25 - 0.50 mm as 2.1 wt.%. The same pattern trend was noticed with the sample TG.

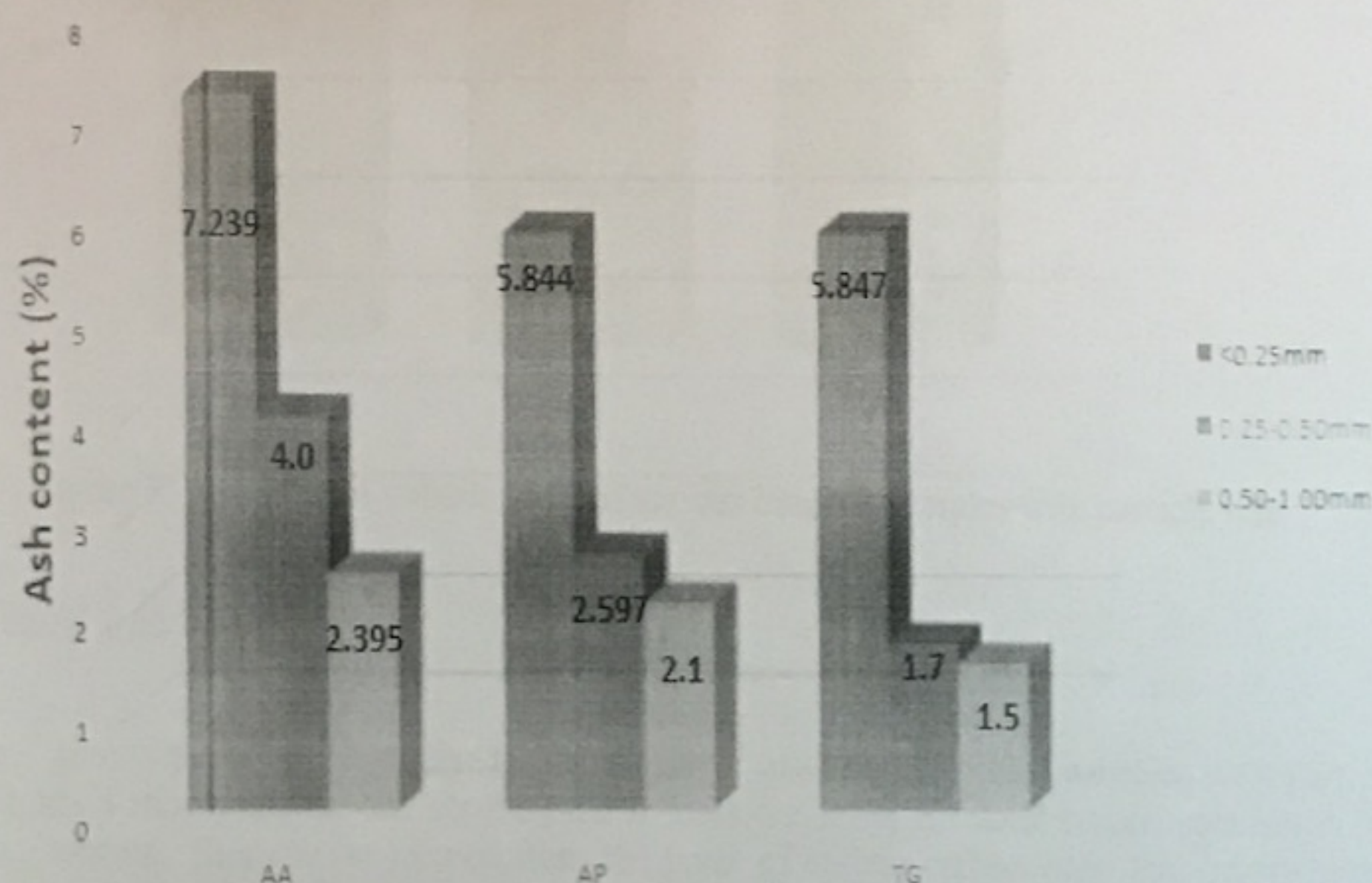


Figure 2: Variation of ash content formation of different biomass samples with particle size

3.3 Volatile matter

Figure 3 shows the variation of volatile yield of various biomass samples with particle size. It shows that volatile yield decreases with increase in particle size [14]. The larger sized particles have better inter-molecular bonding arrangement than the smaller particles, which allows the lignocellulosic composition to be less volatile. However, AA experienced similar volatility, that is, between 0.50 - 1.00 mm having volatile yield of 83.0 wt.% which volatility increases in particle size between 0.25 - 0.50 mm to 84.8 wt. %. The volatile yields suffered similar pattern in AP and TG samples from particle size < 0.25 mm to 1.00 mm. In general, smaller particles tend to undergo more rapid combustion, thus enhance rigorous volatile yields.

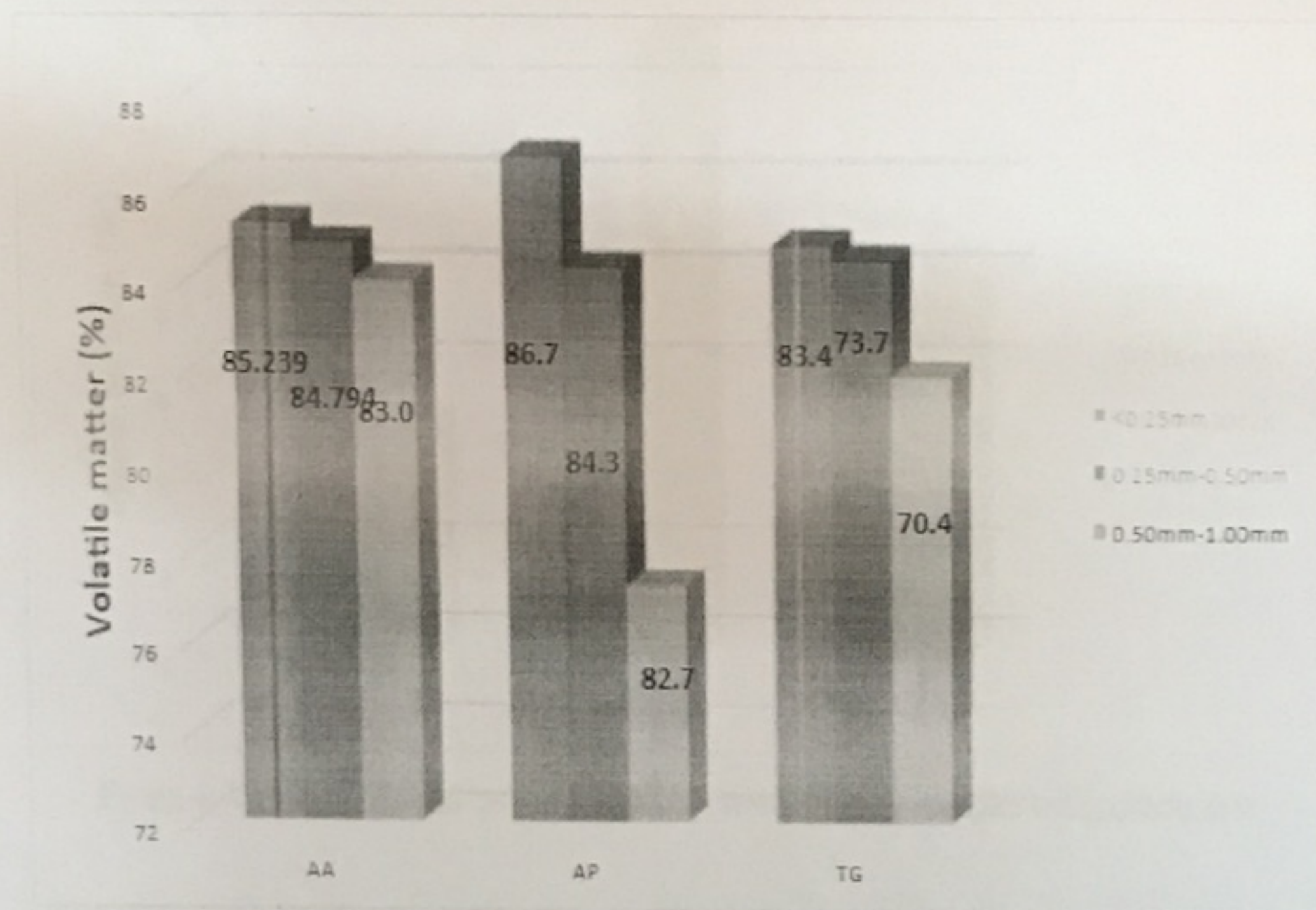


Figure 3: Variation of volatile yield of various biomass samples with particle size

3.4 Fixed carbon content

Figure 4 shows the variation of fixed carbon content of various biomass samples with particle size. Figure 4 shows that the smaller the particle sizes, the lower the fixed carbon contents in the biomass sample. This can be viewed from the point of carbon-carbon bond that exists in the inter-molecular structure of large particle sizes than that of smaller sized particles. This is shown in sample AP with fixed carbon content of 1.98 wt.% for particle size <0.25 mm, which subsequently increases as the particle size increases, that is, at size between 0.25 - 0.50 mm, then increases to 13.82 wt.%.

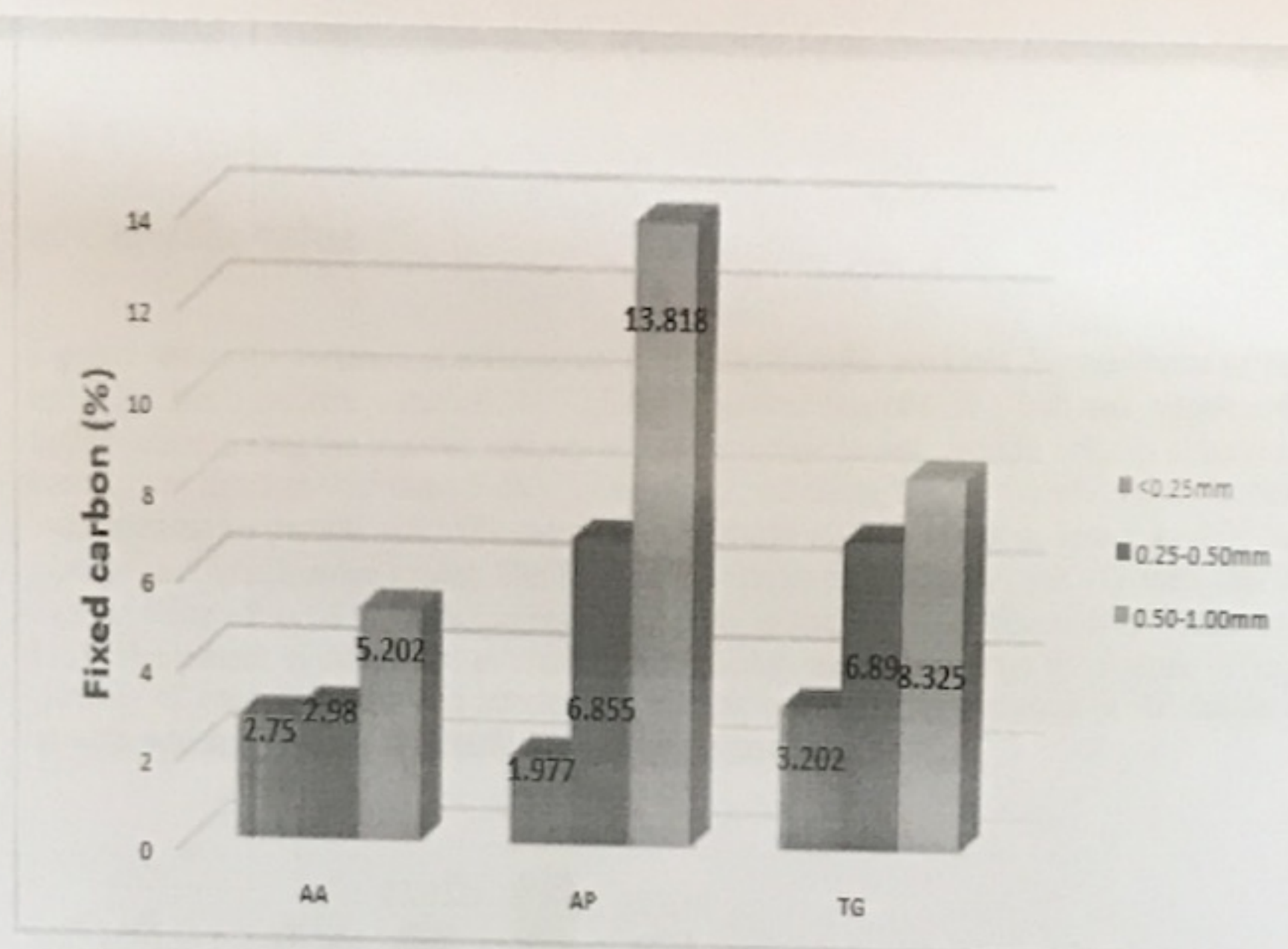


Figure 4: Variation of fixed carbon content of various biomass samples with particle size

3.5 Ultimate analysis

The ultimate analysis of biomass samples gives the common organic contents such as C, H, N, and O available in the biomass sample. Table 1 shows the amount of each element present in the lignocellulosic samples. Sample AP has highest amount of carbon and hydrogen contents, which consequently made AP to have higher gross calorific value than AA and TG. The carbon and hydrogen are usually oxidised during combustion by exothermic reaction to form CO_2 and H_2O , which contribute significantly to gross calorific values. While oxygen has a negative effect on this reaction, hydrogen has a positive effect on the net calorific value, which resulted in the formation of water.

Table 1: Ultimate analysis of biomass samples

Sample	C (%)	H (%)	N (%)	S (%)	O (%)	H:C	O:C
Apa (AA)	55.419	7.083	2.355	0.118	33.838	0.128	0.611
Ara (AP)	61.113	7.343	5.574	0.068	25.902	0.120	0.424
Teak (TG)	60.329	6.979	8.908	0.096	23.689	0.116	0.393

3.6 Calorific value

Figure 5 shows the variation of calorific value of pellet samples produced from different particle sizes. AA has a calorific value of 30.03 MJ/kg at particle size of 0.50 - 1.00 mm, which is the highest value among the biomass samples considered while lowest calorific value is observed at particle size less than 0.25 mm which is 17.12 MJ/kg, indicating that the calorific value increases with increase in particle size. TG has a calorific value of 8.84 MJ/kg at less than 0.25 mm particle size, which is the lowest. The trend of the energy pattern in AA and TG show that the heating value of wood residues increases with particle size; this is established by Tokan *et al* [15]. The pattern in AP is not in conformity with AA and TG, perhaps as a result of large quantity of impurity due to soil interference with lignocellulosic composition of AP during its growth, which is difficult to identify during their preparation.

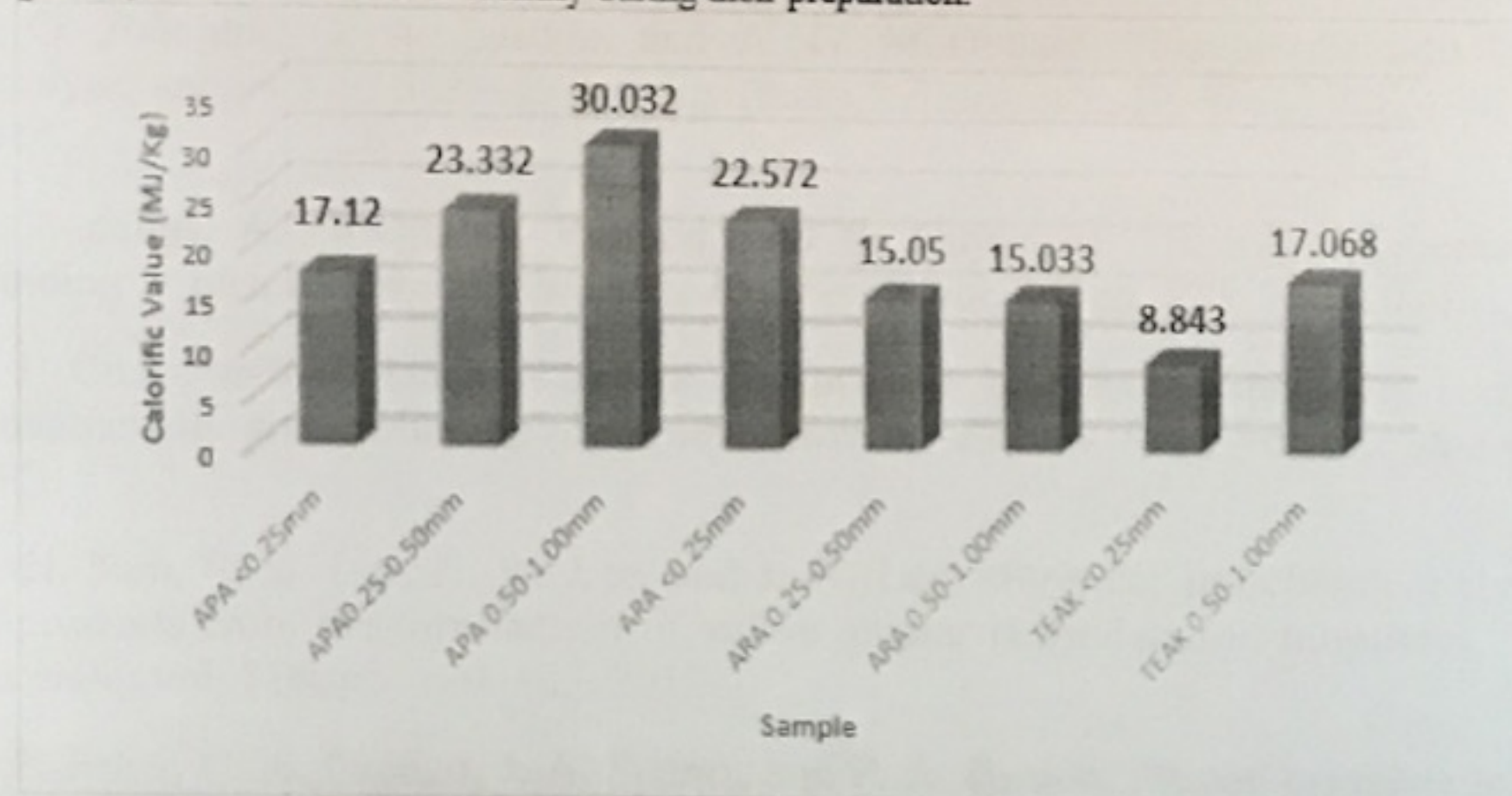


Figure 5: Variation of calorific value of different biomass samples with particle sizes

4 Conclusion

Based on the findings obtained during the research work, it can be concluded that particle size plays a significantly role in combustion properties of woody biomass residues. The analysis so far provides an insight on the energy potential of wood residues as alternative sources of energy fuel. Apa (*Azizelia africana*) AA and Ara (*Albizia pedicellaris*) AP residues seem to have better higher heating value and physico-chemical properties as tests reveal that larger particle sizes of woody biomass would enhance combustion than smaller ones. Also, large sizes of AA wood species are best for energy related uses when compared with AP and Teak (*Tectona grandis*) wood samples.

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