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EFFECT OF DIAMETER AT BREAST HEIGHT OF *LEUCAENA LEUCOCEPHALA* ON BIO CHAR PRODUCTION IN TUBE FURNACE PYROLYSIS

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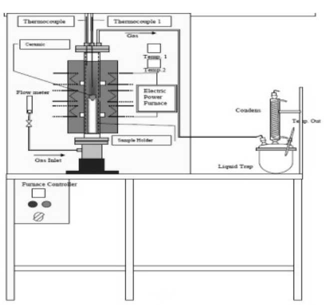
Graphical abstract



Abstract

Renewable energy produced from biomass is a green way to reduce the greenhouse effect. Fast-growing wood species, as the energy source, create independent and fast harvesting cycle for energy fuel stock. The aim of this study was to determine the effect of tree diameter at breast height (DBH) of a local wood species i.e. *leucaena leucocephala*, on char yield during pyrolysis. The calorific value (CV) of bio char was also determined in order to analyse the bio char product produced by pyrolysis process. The tree samples were classified into three DBH i.e. 4, 8 and 12 cm and only tree stem was selected for pelletization. The wood pellets were pyrolyzed at 300, 400, 500, 600 and 700 °C with 40 °C/min of heating rate and holding time of 30 min in inert condition. The largest difference percentage of bio char yield production is only 1 % while the largest difference of CV is 0.7 MJ/kg which happened at temperature 300 °C. In this study, it was found that any DBH does not give any significant effect to the production of bio char as well as its CV.

Keywords: *Leucaena leucocephala,* diameter at breast height (DBH), wood pellet, bio char, calorific value.

1.0 INTRODUCTION

Biomass is generally produced from the waste of agricultural, industrial and domestic activities. Woody materials give a major contribution to the production of biomass energy. Source of woody wastes usually come from sawdust, cutter shavings, off cut and many others. However, recently, supply from wastes for biomass production are shortage and insufficient [1]. Apart of this, the wood waste has problem to be reused due to its impurities where it contains hazardous additives. For example, wood wastes generated from laminating or particle board industries, often contain UF, PF and MF resins which may release or emit toxic gases when directly burnt. In particle board or laminating flooring industry, wood waste contains phenol-formaldehyde (PF), melamine-formaldehyde (MF) and urea-formaldehyde (UF) resin which emits toxic gases when burned. As for solid wood industry such as timber manufacturing, it has been chemically treated for the preservation process. Treatment agents used are usually from chemical solvents such as boric acid and CCA (chromate, copper and arsenate). These entire hazardous chemical give side effect to the environment and human health. For example, wood waste which contains aminoplasts resins when subjected to thermo-chemical conversion will emit toxic gases such as ammonia, isocyanic and hydrocyanic acid and nitrous oxides thus will cause pollution [2][3][4][5]. To ensure a more secure supply and less hazardous source, plantation forestry for shorterm rotation (fast maturity) energy crop purpose is needed to be are promising and sustainable. Malaysia has a lot of former logging and mining sites where these sites can be used for energy crop. For short-term rotation plantation, poplar and willow a popular choice while some researches focused to use birch and alder [6][7][8]. In Malaysia there are wide range which is suitable for shorterm rotation plantation species that suit the tropical climate, for example *Leucaena leucocephala* (LL), locally known as petai belalang. This species is fast growing and gives high density of yield for biomass resource. LL has been planted in Malaysia for animal feeding [9], potential slope plantation for prevent soil erosion [10] and for raw material for wood industry for engineered wood industry [11]. In addition, this woody material has high potential as biomass fuel. In energy crop plantation, shorterm rotation and high yield are the main criteria as a potential raw material for producing the biomass fuel [12]. V. Singh and O. P Toky has reported that LL give high production of biomass yield than natural forest of India (18 to 22 t ha^{-1} $year^{-1}$) and some agroforestry system (20 to 26 t ha^{-1} $year^{-1}$). The authors also reported 4 years old of LL can produce up to 33 t ha^{-1} $year^{-1}$ of yield [13]. Tree DBH normally increases during growth, however, the growth rates are different for individual due to various factors such as soil condition, genetic, light, temperature, water (humidity) and nutrition. Higher tree DBH often indicates increase of woody yield and specific gravity, but the effect on biomass characteristic need to be analyse further. Since fast harvesting give better source recovery, small DBH or younger tree will give the advantage in material supply. As for specific gravity factor, higher value will give better energy density and bio char yield when subjected to pyrolysis [14].

2.0 MATERIAL AND METHOD

LL sample were classified into 3 different DBH i.e. 4, 8 and 12 cm and only the tree stem were collected. After the cutting process, the tree stems were chipped using mobile chipper. Since fresh wood is high in moisture content, wood chips were open air dried for 3 days until the moisture content reduced to around 12 % from originally. The drying phase is important to soften the wood chip and optimum production of pelletizing can be achieved when the wood chip MC is within range 10 to 12 % MC. The next phase will be the grinding process where disc mill machine was used. The machine consists of sieving plate and for this study; sieve plate with 2 mm diameter size was selected. The size of sieve chosen produced wood particles that are best for pelletizing. After grinding, pelletization of wood particles was carried out to produce 2 mm diameter of pellet. To ovoid moisture increasing, pellet keep in thigh screw bottle.

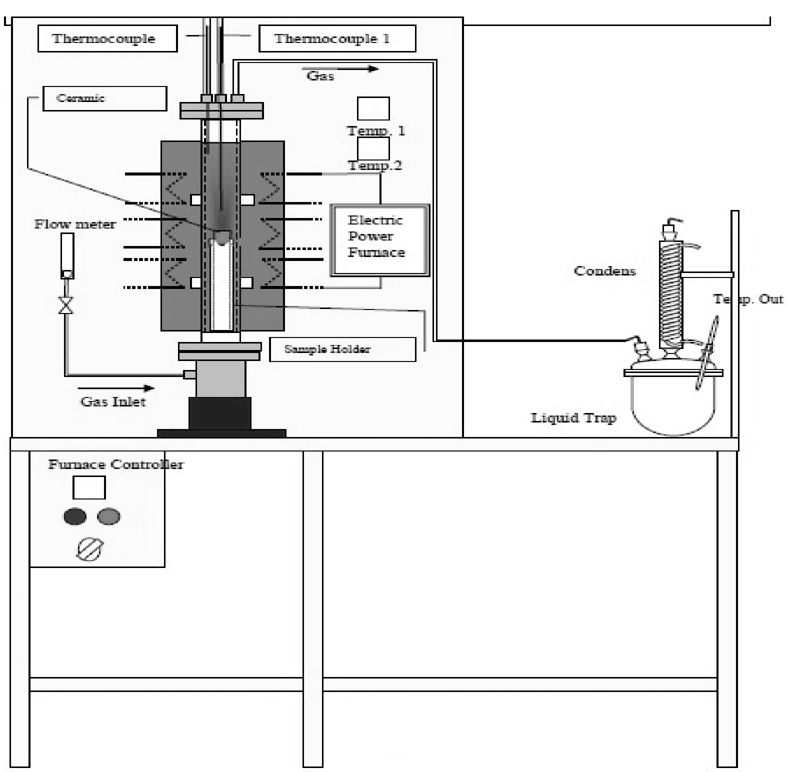


Figure 1 Tube furnace schematic diagram

In pyrolysis process, tube furnace was used as shown in Figure 1. 10 grams of pellets were weight and added into the porcelain crucible. Pure nitrogen (99.9 %) gas purged through tube furnace with flow rate of 250 ml/min for 30 minutes to ensure inert condition. After inert condition has been achieved, pyrolysis process was carried out with constant flow rate of 150 ml/min. In this study, the heating rate applied was the highest rate that the furnace can run which is 40 °C/min. Highest heating rate will achieve target temperature with shorter time and electrical energy saving. Once the target temperature is achieved 300, 400, 500, 600 and 700 °C, the holding time for pyrolysis was 30 minutes. The data of proximate and ultimate analyses of raw material of *LL* are shown in Table 1.

Table 1 Chemical properties of raw *leucaena leucocephala*

Proximate Analysis (db)					
DBH (cm)	**Element (wt %)**				**CV (MJ/kg)**
	Volotile Matter	**Fixed Carbon**	**Ash**		
4	87.1	12.5	0.8		20.3
8	86.8	12.4	0.8		20.0
12	86.7	12.4	0.8		20.0
Ultimate Analysis (daf)					
DBH (cm)	**Element (wt %)**				
	Carbon	**Hydrogen**	**Nitrogen**	**Sulfur**	**Oxygen (*)**
4	46.1	6.3	2.2	0	45.4
8	44.9	6.4	2.5	0	46.2
12	45.1	6.9	2.2	0	45.8

db – dry basic, daf – dry ash free basic, * calculate by difference

3.0 RESULTS AND DISCUSSION

As shown in Figure 2, generally the highest solid yield was produced at 300 °C; where 4 cm DBH with 81 % has slightly lower percentage of 1 % as compared to 8 cm and 12 cm DBH with 82 %. However from physical observation, bio char produced at this temperature were not fully pyrolyzed. Some researcher categorised this temperature within torrefaction level. At temperature 400 °C solid yield drop drastically to 36 % for 4 cm DBH, 37 % for both 8 cm and 12 cm DBH. The result showed slight difference of 1 % for 4 cm DBH compared to other two DBHs. For this temperature, bio char were fully pyrolyzed and the solid yields were totally black in colour. This result is due to effective decomposition of the three wood components which are cellulose, hemicellulose and lignin, where approximately 63 % of total wood pellet mass were evaporated as liquid and gas products. As temperature of pyrolysis is increasing from 500 to 700 °C, bio char yield from all DBHs reduces from 28 % (500 °C) to 23 – 24% (600 °C) and finally to 22 – 23 wt % (700 °C). This is due to further decomposition of samples to liquid (tar) and gaseous products.

Overall, pyrolysis temperature of 300 °C produced incomplete thermal conversion of raw *LL* to its Bio char state. Complete decomposition is achieved at higher temperature and as temperature of pyrolysis is increased, lower bio char yield is achieved as shown in Figure 2. It can be observed that difference in tree DBHs does not have significant effect on bio char yield.

For temperature 500 °C all three DBHs drops to 28 %b bio char yield. When wood pellet pyrolyzed into higher temperature at 600 °C, char yield drop into 23 % for DBH 4 cm and 24 % for both 8 cm and 12 cm. At temperature 700 °C char yield only differ 1 to 2 % from 600 °C char yield with 22 % for DBH 4 and 8 cm while 23 % for DBH 12 cm. In overall, char yield was dropped drastically from 300 to 400 °C. Then the trend was slightly reduced from 500 to 700 °C. The result shows that tree DBH gave not significant effect on bio char yield. Calorific values for raw wood pellet showed 20.3, 20.0 and 20.0 MJ/kg for DBH 4, 8 and 12 cm respectively. From Figure 3, DBH of 4 cm showed slightly higher value of CV coverage due to higher percentage of bark as compared to other DBHs. For temperature 300 °C, CV for DBH 4, 8 and 12 cm were 21.4, 20.7 and 21.1 MJ/kg respectively. It can be seen that there was a slight increment of approximately 1 MJ/kg where at this stage, surface moisture was evaporated and the three wood chemical components started to decomposed. At temperature 400 °C, CV of bio char increased up to 39 % with 29.3 MJ/kg for DBH 4 cm while other DBHs of similar share the same value of 28.7 MJ/kg. At this stage, the pyrolysis process produced solid product with high carbon content. When the temperature level raised up to 500 °C, both DBH 8 and 12 cm increase approximately 2 MJ/kg but for DBH 4 cm with only 1 MJ/kg . The trend same goes to when the temperature became 600 °C, CV slightly increased up to 6 % where CV are 31.9 MJ/kg for DBH 4 cm, 31.8 MJ/kg for DBH 8 cm and 32.4 MJ/kg for DBH 12 cm. At final temperature level of 700 °C, CV for DBH 4 and 12 cm was slightly dropped with 0.3 MJ/kg respectively and no CV changes for DBH 8 cm. In other word, there were no significant CV changes at temperature 600 and 700°C where the value obtained was around 32 MJ/kg for all three DBH.

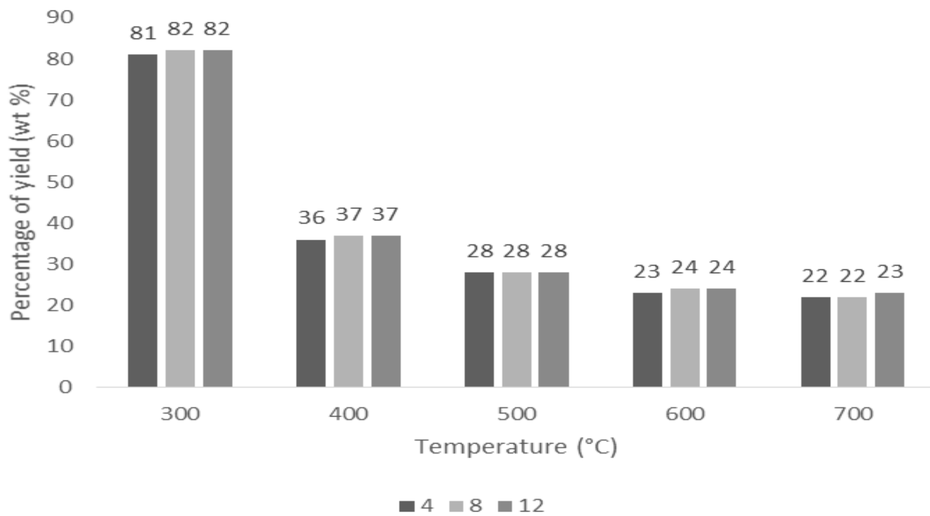


Figure 2 Bio char yield with different DBH and pyrolysis temperature

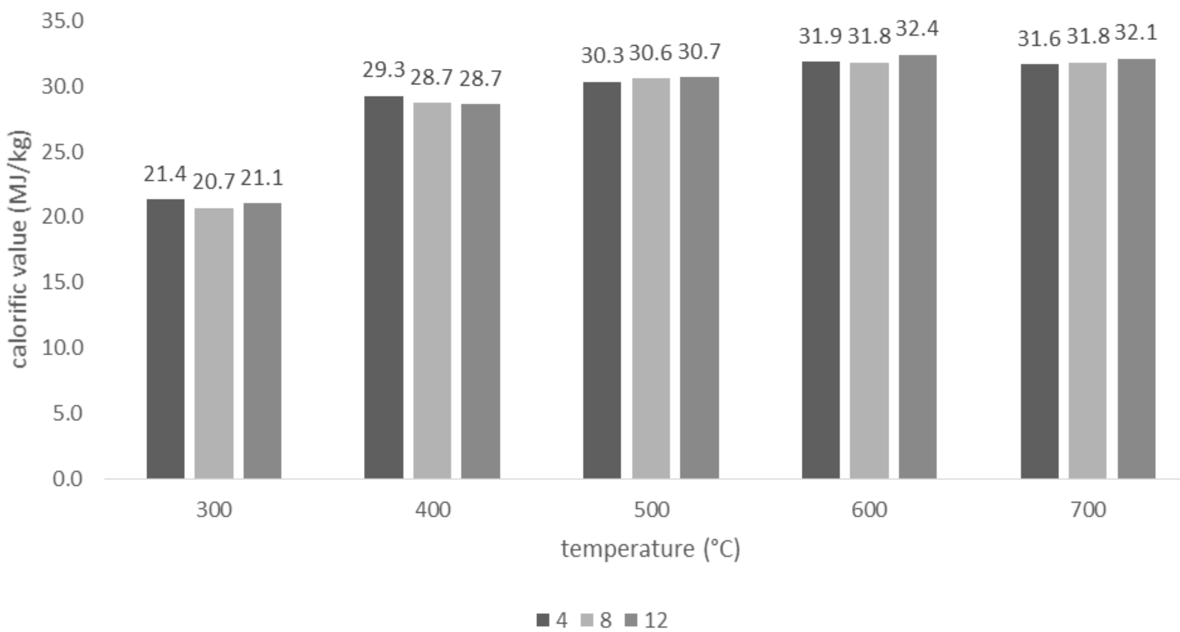


Figure 3 Calorific value of bio char with different DBH and pyrolysis temperature

4.0 CONCLUSION

Leucaena leucocephala has high potential to be harvested as energy crop plantation due to its comparatively high CV. From the study it can be concluded that small DBH of tree (young *LL)* has no significant difference compared to larger DBH (older *LL)* in term of bio char production and it's CV. It can be concluded that, in producing bio char, small DBH can be used thus this will give advantage in fast harvesting and recovering of energy crop. However, pyrolysis temperature of 400 °C and higher are preferable in producing bio char. It can be concluded that preferable as higher bio char yield and CV value obtained.

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