NOTE

PHYSICO–CHEMICAL PROPERTIES OF WOOD PELLETS FROM FOREST RESIDUES

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ACDA MN & DEVERA EE. 2014. Physico–chemical properties of wood pellets from forest residues. The study investigated the physical, chemical and combustion properties of wood pellets from forest residues. Wood shavings from mixed *Dipterocarpaceae* species and branch wood of *Gmelina arborea* and *Leucaena leucocephala* were used as feedstock. Ultimate, proximate, elemental and combustion analyses were performed to assess pellet quality in accordance with DIN 51731 (1996) for compressed solid fuel. In general, forest biomass used in this study formed pellets that were homogenous with uniform size and shape. Moisture content, particle density, bulk density and abrasion resistance were all within guiding values of the standard. Pellet samples used in this study showed relatively low levels of ash forming elements and heavy metals with calorific values suitable for industrial and residential heating applications. Combustion analyses of pellets from shavings and branch wood also showed that these materials burned freely and continuously while maintaining their integrity during the burning cycle. Low levels of pollutant emissions were detected when pellets were burned from biomass samples used in this study.

Keywords: Renewable energy, biomass, *Gmelina arborea*, *Leucaena leucocephala*

INTRODUCTION

The threat of climate change due to global atmospheric pollution caused by emissions from the use of fossil fuels has resulted in worldwide interest in using biomass to produce heat, power and liquid fuels (Heinimo & Junginger 2009). The use of biomass for energy production is considered carbon neutral provided that harvesting is conducted from a sustainably managed source. One of the most promising alternatives for utilisation of biomass is heat source in the form of fuel pellets (Di Giacomo & Taglieri 2009). Wood pellets are compressed solid fuel of high density and high combustion efficiency. Their geometry and cylindrical form facilitate transport over long distances, compact storage and control feeding to burners and boilers (Hartmann & Lenz 2012). Its high energy density (18–20 MJ kg^{-1}) makes it suitable for both commercial and industrial heating applications (Obernberger & Thek 2004). Emissions such as NO_x, SO_x and volatile organic compounds from pellet burning equipment are also very low in comparison with fossil fuels (Olsson & Kjallstrand 2004, Klason & Bai 2007). These attractive properties have resulted in soaring demand for fuel pellets in Sweden, Finland, Italy, USA, UK, Canada, Korea and Japan (Stahl & Wikstrom 2009, Heinimo & Junginger 2009).

The Philippines generates millions of cubic meters of woody biomass and forest residues that are widely available and can be converted to heat for power generation and energy requirements (Samson et al. 2001). These residues are usually discarded or inefficiently used as boiler fuel in many processing plants. With current residue production levels in the Philippines, it has been estimated that biomass residue can supply approximately 160 MW to the national grid if efficient biomass energy conversion technologies are developed (Anonymous 1993). Unfortunately, despite the increasing popularity of wood pellets for industrial and residential heating applications in many countries, limited study of the use of wood as fuel pellet has been

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conducted in the Philippines. One potential approach to stimulate the development of wood pellet industry in the Philippines is to utilise fast-growing plantation tree species (e.g. *Eucalyptus, Gmelina*) and other ligno-cellulosic fibres in the production of fuel pellets. Wood pellets could be used in power generating plants utilising coal co-fired with traditional biomass fuel for industrial and residential heating applications. Such developments can result in significant fuel savings with positive impact on the environment. The present study reported on the physical, chemical and combustion properties of wood pellets from Philippine forest residues. Properties of these materials are different from stem wood and basic information on fuel characteristics is necessary for the production of quality pellets from this feedstock.

MATERIALS AND METHODS

Forest residues

Dry wood shavings were collected from the furniture manufacturing plant of Pacific Timber Corporation in Bulacan province. The shavings were from mixed Philippine hardwood (Dipterocarpaceae) from various surfacing operations of the plant. Branches of mature *Gmelina arborea* and *Leucaena leucocephala* that are often left in the forest after logging or harvesting operations were collected in Mt Makiling, Laguna for use as feedstock in this study. Bark of *G. arborea* and *L. leucocephala* branches were removed prior to particle preparation. All residues were chipped or/and hammermilled to a particle size of 4–6 mm and dried in a rotary drier (80–110 °C) to about 16% moisture content prior to the pelleting operation.

Pelleting process

Dry woody biomass were pressed using a laboratory pelletiser at a uniform rate through the holes of a fix ring die (8 mm) and rotating roller cylinder. Binders or lubricants were not used to consolidate or increase the strength of pellets. When the pelleting process reached a stable temperature (85 °C), sample pellets were randomly collected and cooled in ambient air before storing in plastic container prior to physical and chemical testing.

Physical and chemical analysis

Pellets were randomly selected from each trial for measurement of physical and chemical properties. Average values of diameter, length and weight as well as ratio of length/diameter were measured from 20 randomly selected individual pellets. Particle density was calculated from the average weight and volume of individual pellet. Bulk density was calculated using the weight and volume of pellets from 1000 mL graduated cylinder. Pellet properties were compared with guiding values of DIN 51731 (1996) for compressed solid fuel to assess their quality and suitability for thermal energy conversion.

Proximate, ultimate and elemental analyses were conducted using 10 pellets randomly selected from each trial. Proximate analysis consisted of determination of moisture, ash content and volatile matter following procedure of ASTM E870 (ASTM 1998). Fixed carbon content was obtained by difference of the sum of volatile matter, moisture and ash content. Gross calorific values were measured at constant volume in dry basis using an isoperibol bomb calorimeter (ASTM 2004). Net calorific value of pellets was calculated using the equation

$$NCV = GCV - 0.02441\ M$$

where NCV = net calorific value, GCV = gross calorific value, 0.0244 = latent heat of vaporisation of water at 25 °C and M = hydrogen content concentration (%) of raw material (Kuokkanen et al. 2009). Three replicates were used for each calorific measurement.

Ultimate analysis for the presence of C, N, and S was performed using an organic elemental analyser (Dumas combustion method) in an oxygen-enriched helium atmosphere attached to a stable isotope ratio mass spectrometer. Oxygen content was obtained by difference of the sum of C, H, N and S contents. Elemental analyses for the presence of heavy metals (Cd, Pb, Zn, Cr, Cu) and other trace elements (Mg, Ca, Fe, K and P) were determined using atomic absorption spectroscopy.

Combustion analysis

Pellet burning experiments were conducted in the laboratory using the method described by

Olsson et al. (2004) with minor modifications to simulate ignition, flaming and glowing phases of combustion. Excess air was used to maintain pyrolytic reactions and detect emissions. Four pellets from wood shavings and branch wood of *G. arborea* or *L. leucocephala* were placed on a perforated steel plate under a 20 cm high aluminum sheet cone. The pellets were set aflame from below using a butane torch while allowing air to flow freely through the plate and cone. Time sequence of combustion stages (initial smoldering, flaming, after flame smoldering and final glowing) was measured. Flame characteristics and combustion behaviour were recorded for each type of pellet. Smoke samples were collected at each stage and analysed using a gas analyser for volatile hydrocarbons, carbon dioxide (CO_2,), carbon monoxide (CO) and oxygen (O_2). Temperatures were measured at each stage using infrared thermometer.

Abrasion resistance

The abrasion resistance of pellets from selected trial was determined using a four sided (12 cm × 30 cm) rotating chamber (15 rpm) to induce particle collisions against one another and the walls of the chamber. About 100 g pellets were tumbled for 60 s. After the tumbling period abraded fines were collected and the remaining pellets in the test chamber removed and weighed. Abrasion resistance was expressed as percentage of the weight of the pellets remaining in the chamber to initial pellet weight. Results were compared with guidelines of the ÖNORM M7135 (2000) to assess quality and suitability for fuel pellets. Five replicate abrasion measurements per sample were performed.

RESULTS AND DISCUSSION

Physical properties

Wood pellets from Philippine forest residues had fairly uniform and relatively homogenous diameter and length (Table 1). Pellet temperature directly after pelleting was about 85 °C. Density of the pellet particles from shavings and branch wood met the guiding value of > 1.12 g cm^{-3} (DIN 51731 1996). Particle density influences bulk density and combustion behaviour; dense particles have longer burnout time (Obernberger & Thek 2004). Bulk density of wood pellets obtained in this study ranged from 618 to 788 kg m^{-3}. Bulk densities of all pellet samples used in this study were above the guidelines of the DIN 51731 (1996). High bulk density has positive effect on energy density, transportation costs and storage capacity both for pellet producers and end users.

Proximate analysis

Results of proximate analysis showed that all pellet samples used in the study had moisture contents less than 10% after the pelleting operation (Table 2). Pellets from branch wood of *G. arborea* and *L. leucocephala* showed significantly higher ash contents (1.41 and 2.83% respectively) compared with pellets from wood shavings (0.49%). The reason for the higher ash content of the branch wood is unclear but similar results were reported by Lehtikangas (2001). Feedstock with high ash contents is generally not suitable for thermal conversion due to problems associated with ash removal, slagging, corrosion of equipment and deposit formation

Table 1 Physical characteristics of wood pellets from Philippine forest residues

Property	Shavings (Mixed hardwood)	Branch wood (*Gmelina arborea*)	Branch wood (*Leucaena leucocephala*)	Guiding value DIN 51731 (1996)
Diameter (mm)	8.64	8.21	8.22	4–10
Length (mm)	21.26	34.65	26.04	< 50
Moisture (%)	5.10	3.41	4.15	< 12
Particle density (g cm^{-3})	1.20	1.27	1.27	> 1.12
Bulk density (kg m^{-3})	618.1	645.50	787.90	> 600
Abrasion (wt %)	1.49	1.27	0.76	< 2.3*

*Based on ÖNORM M7135 (2000)

Table 2 Proximate analyses of wood pellets from Philippine forest residues

Property	Shavings (Mixed hardwood)	Branch wood (*Gmelina arborea*)	Branch wood (*Leucaena leucocephala*)	Guiding value DIN 51731 (1996)
Moisture (%)	7.32	6.56	7.12	< 12
Ash (%)	0.49	1.41	2.83	< 1.5
Volatile matter (%)	76.32	68.59	64.12	-
Fixed carbon (%)	15.87	23.44	25.93	-
Gross calorific value (MJ kg^{-1})	19.13	18.34	19.08	-
Net calorific value (MJ kg^{-1})	18.99	18.20	18.93	17–19

in the furnace (Obernberger et al. 2006, Rhen et al. 2007). High ash content feedstock may also result in high level of operating discomfort among home owners when used for residential heating. Volatile matters in shavings and branch wood were about 64–76%. Volatile matter strongly influences thermal decomposition and combustion behaviour of solid fuels (Olsson et al. 2003, 2004). Results of the study indicated that wood shavings had slightly higher level of volatile matter compared with branch wood of *G. arborea* and *L. leucocephala*. The higher the proportion of volatile matter, the more suitable the feedstock for thermal conversion (Olsson et al. 2004, Holt et al. 2006). Similarly, higher net calorific value also indicates that the pellet is suitable to be used as feedstock (Laxamana 1984, San Luis et al. 1984). Net calorific value in this study was 18 $MJkg^{-1}$, i.e. within the minimum requirements of DIN 51731 (1996) for solid fuel for industrial heating processes. Similar ranges of heating values have been reported for several hardwood (Telmo & Lousada 2011).

Ultimate analysis

All samples contain high proportion of C, H and O indicating high energy potential of the pellets (Table 3). C, H and O are the main components of biomass feedstock and the main reactants in combustion process (Shafizadeh 1984). All samples also showed low levels of N and S as required by the DIN 51731 (1996). These imply that very low levels of NO_x and SO_x will be emitted if these pellets are used in thermal conversion processes.

Elemental analysis

Minor and trace elements of pellets from Philippine forest residues are shown in Table 4. These inorganic elements influence ash formation and the melting behaviour, emission, utilisation and disposal of ashes. Low levels of ash-forming elements were present in pellets from shavings and branch wood of *G. arborea*. However, pellets from branch wood of *L. leucocephala* had slightly higher levels of ash-forming elements in comparison with shavings and branch wood of *G. arborea*. The results agree with the results of proximate analysis (Table 2). The relatively small amount of ash forming elements in all samples tested indicate that pellets can be used for industrial heating requirements where problems associated with slagging, fouling and sintering formation are important. Content of heavy metals such as Pb, Cd and Cr are very small and within the guidelines of the DIN 51731 (1996). Low levels of heavy metals in wood pellets are important because they have strong impact on ash quality, particulate emissions and ash recycling and disposal (Lehtikangas 2001, Obernberger & Thek 2004, Obernberger et al. 2006).

Combustion analysis

Analyses of emissions during combustion of pellets show that smoke consisted mainly of volatile hydrocarbons, CO_2, CO, and O_2 (Table 5). Volatile hydrocarbons from burning wood pellets consist mainly of aromatic hydrocarbons, methoxyphenols and other aromatic compounds (Olsson et al. 2003, 2004). The flaming phase consumed 80–85% of biomass burned and the final glowing phase, the remaining 15–20%. High concentrations of volatile hydrocarbons and CO_2 were observed during the initial and after flame smoldering phases. Low levels of CO were measured in all phases of combustion. Initial and after flame smoldering are considered transition phases with significant contribution to pollutant emissions (Olsson et al. 2004). Duration of each phase varied according

Table 3 Ultimate analyses of wood pellets from Philippine forest residues

Element (wt %)	Shavings (mixed hardwood)	Branch wood (*Gmelina arborea*)	Branch wood (*Leucaena leucocephala*)	Guiding value DIN 51731 (1996)
C	48.05	47.62	45.68	48–50
H	5.61	5.51	5.79	6.2
O	47.96	47.51	48.18	42
N	0.37	0.35	0.41	< 0.3
S	0.06	0.03	0.04	< 0.08

Table 4 Elemental analyses of wood pellets from Philippine forest residues

Element (mg kg^{-1})	Shavings (mixed hardwood)	Branch wood (*Gmelina arborea*)	Branch wood (*Leucaena leucocephala*)	Guiding value DIN 51731 (1996)
Na	3.17	8.13	3.86	-
Mg	2.48	1.48	2.06	-
P	55	41	43	-
K	424	283	566	680
Ca	483	338	514	< 493
Mn	8.28	24.15	8.24	-
Fe	648.4	255.6	565	-
Cr	< 0.413	0.71	1.21	< 8
Cu	8.28	15.62	11.77	< 5
Zn	125	44	38.35	< 100
Cd	< 0.13	< 0.14	< 0.11	< 0.5
Pb	0.24	0.85	0.71	< 10

Table 5 Emissions from burning wood pellets from Philippine forest residues

Phase of combustion	Shavings (mixed hardwood)				Branch wood (*Gmelina arborea*)				Branch wood (*Leucaena leucocephala*)			
	VHC (ppm)	CO_2 (%)	CO (%)	O_2 (%)	VHC (ppm)	CO_2 (%)	CO (%)	O_2 (%)	VHC (ppm)	CO_2 (%)	CO (%)	O_2 (%)
Initial smouldering	20	2.83	0.01	14.7	55	0.50	0.07	20.4	7.0	1.61	0.02	20.5
Initial flaming	118	5.34	0.32	16.1	37	0.42	0	20.4	11	3.67	0.01	16.2
Final flaming	37	0.87	0.60	19.7	14	0.64	0	20.0	13	6.01	0.01	14.3
After flame smouldering	89	1.17	0.29	19.6	26	2.78	0	17.8	17	6.20	0.01	14.2
Final glowing	64	0.96	0.16	20.7	4	1.29	0.02	19.4	36	2.70	0.09	18.0

VHC = volatile hydrocarbons

to the type of pellet but, in general, initial smoldering, flaming (initial and final), after flame smoldering and final glowing lasted about 1 min, 2–3 min, 2–3 min and 3–7 min respectively. Wood pellets from shavings and branch burned freely and continuously and the pellets retained their integrity during the burning cycle. These observations agree with results from the proximate and ultimate analyses (Tables 2 and 3) whereby feedstock used in this study contains sufficient thermal energy for commercial and industrial heating applications.

Abrasion resistance

All pellet samples from shavings and branch wood had abrasion resistance of < 2.3% and passed the guiding value of the ÖNORM M7135 (2000) (Table 1). Abrasion resistance is an important pellet parameter since high levels of fines in storage system can cause clogging and failures in feeding systems. Low level of fines is also essential for convenience of end users to prevent dust emissions during combustion.

CONCLUSIONS

In general, shavings and branch wood used in this study formed pellets that were homogenous with uniform size and shape. Physical properties were all within guiding values set by the DIN 51731 (1996). Calorific values of pellets from shavings and branch wood of *G. arborea* and *L. leucocephala* had thermal energy of about 18 MJ kg^{-1}. This is within the requirements of the DIN 51731 (1996) for commercial and industrial heating applications. However, proximate analyses of pellet from branch wood of *G. arborea* and *L. leucocephala* showed slightly elevated ash content which might present problems associated with ash removal, slagging, corrosion of equipment and deposit formation in the furnace. Pellets from wood shavings showed properties suitable for industrial and residential heating requirements. Combustion analyses also showed that wood pellets from shavings and branch wood burned completely and continuously while retaining their integrity during the burning cycle. Low levels of CO were released when all pellet samples were burned.

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REFERENCES

Anonymons. 1993. *Philippines: Commercial Potential for Power Production From Agricultural Residues*. No. ESM 157/93. World Bank, Washington DC.

ASTM E870 1998. *Standard Test Methods for Analysis of Wood Fuels*. American Society for Testing and Materials, West Conshohocken.

ASTM E711. 2004. *Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter*. American Society for Testing and Materials, West Conshohocken.

Di Giacomo G & Taglieri L. 2009. Renewable energy benefits with conversion of woody residues to pellets. *Energy* 34: 724–731.

DIN 51731. 1996. *Testing of Solid Fuels—Compressed Untreated Wood, Requirements and Testing*. Deutsches Institut fur Normung, Berlin.

Hartmann H & Lenz V. 2012. Biomass energy heat provision in modern small-scale systems. Pp 1351–1400 in RA Myers (ed) *Encyclopedia of Sustainability Science and Technology*. Springer, New York.

Heinimo J & Junginger M. 2009. Production and trading of biomass for energy—an overview of the global status. *Biomass and Bioenergy* 33: 1310–1320.

Holt GA, Blodgett TL & Nakayam FS. 2006. Physical and combustion characteristics of pellet fuel from cotton gin by-products produced by select processing treatment. *Industrial Crops and Products* 24: 204–213.

Kuokkanen M, Kuokkanen T, Stoor T, Niimaki J & Pohjonen V. 2009. Chemical methods in the development of eco-efficient wood-based pellet production and technology. *Waste Management and Research* 27: 561–571.

Klason X & Bai S. 2007. Computational study of the combustion process and NO formation in a small-scale wood pellet furnace. *Fuel* 86: 1465–1474.

Laxamana NB. 1984. Heating value of some Philippine woods, non-woods and barks. *FPRDI Journal* 8: 6–12.

Lehtikangas P. 2001. Quality properties of pelletized sawdust, logging residues and bark. *Biomass and Bioenergy* 20: 351–360.

Obernberger I & Thek G. 2004. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behavior. *Biomass and Bioenergy* 27: 653–669.

Obernberger I, Brunner T & Barnthaler G. 2006. Chemical properties of solid fuels—significance and impact. *Biomass and Bioenergy* 30: 973–982.

Olsson M & Kjallstrand J. 2004. Emissions from burning of softwood pellets. *Biomass and Bioenergy* 27: 607–611.

Olsson M, Kjallstrand J & Peterson G. 2003. Oxidative pyrolysis of integral softwood pellets. *Journal of Analytical and Applied Pyrolysis* 67: 135–141.

Olsson M, Ramas O & Peterson G. 2004. Specific volatile hydrocarbons in smoke from oxidative pyrolysis of softwood pellets. *Journal of Analytical and Applied Pyrolysis* 71: 847–854.

ÖNORM M7135. 2000. *Compressed Wood and Compressed Bark in Natural State—Pellets and Briquettes, Requirements and Tests Specifications*. Austrian Standard Institute, Vienna.

Rhen C, Ohman M, Gref R & Wasterlund I. 2007. Effect of raw material composition in woody biomass pellets on combustion characteristics. *Biomass and Bioenergy* 31: 66–72.

Samson R, Helwig T, Stohl D, De Maio A, Duxbury P, Mendoza T & Elepano A. 2001. *Strategies for Enhancing Biomass Energy Utilization in the Philippines*. National Renewable Energy Laboratory, Golden, San Luis JM, Briones LP & Estudillo CP. 1984. An evaluation of giant Ipil-ipil for charcoal production and briquetting. *FPRDI Journal* 8: 31–40.

Shafizadeh F. 1984. The chemistry of pyrolysis and combustion—the chemistry of solid wood. Pp. 489–529 in Rowell, RM (ed) *Advances in Chemistry Series* Number 207. American Chemical Society, Washington DC.

Stahl M & Wikstrom F. 2009. Swedish perspective on wood fuel pellets for household heating: a modified standard for pellets could reduce end-user problems. *Biomass and Bioenergy* 33: 803–809.

Telmo C & Lousada J. 2011. Heating values of wood pellets from different species. *Biomass and Bioenergy* 35: 2634–2639.