ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 12 N° 1 2016
pp. 51-57

CALORIFIC PROPERTIES OF WASTES FROM SOME EXOTIC WOOD SPECIES

Aurel LUNGULEASA
Transilvania University of Brasov, Faculty of Wood Engineering
Address: Str. Universităţii nr. 1, 500068 Braşov, România
Tel: 0040 268 419581, Fax: 0040 268 419581, E-mail: lunga@unitbv.ro

Camelia COŞEREANU
Transilvania University of Brasov, Faculty of Wood Engineering
Address: Str. Universităţii nr. 1, 500068 Braşov, România
Tel: 0040 268 419581, Fax: 0040 268 419581, E-mail: cboieriu@unitbv.ro

Cosmin SPÎRCHEZ
Transilvania University of Brasov, Faculty of Wood Engineering
Address: Str. Universităţii nr. 1, 500068 Braşov, România
Tel: 0040 268 415315, Fax: 0040 268 415315, E-mail: cosmin.spirchez@unitbv.com

Tatiana DOBREV (GRÎU)
Transilvania University of Brasov, Faculty of Wood Engineering
Address: Str. Universităţii nr. 1, 500068 Braşov, România
Tel: 0040 268 415315, Fax: 0040 268 415315, E-mail: griu.tatiana86@gmail.com

Abstract:
This paper aims to present some results about the calorific properties of biomass wastes from exotic species used as fuels. There are presented the main characteristics of biomass energy, respectively the low and high calorific value, burning speed and energy efficiency. Methodology takes into consideration the equipment, wooden species and relationships for calorific determination. The final conclusion resulting from the experiments is that the biomass of exotic species is as good as any other woody biomass, when is used as fuel, because the calorific properties are closely, even slightly higher than of classical fuels.

Key words*: biomass; exotic wood species; calorific value; calorific density; calorific efficiency.*

INTRODUCTION

In the last years, the researchers are more and more focused on the use of woody biomass as solid fuels (Demirbas and Demirbas 2004, Profft *et al*. 2009, Vamvuka 2011, Verna *et al*. 2009), to be used both for large and small thermal furnaces, and also for rural stoves (Aghamohammadi *et al*. 2011, Bhattacharya and Abdul 1989, Boutin *et al*. 2007, Jehlickova and Morris 2007, Lundborg 1998, Moya and Tenorio 2013, Okelo *et al*. 2013, Prasertsan and Sajakulnukit 2006). There are several advantages of using woody biomass, such as the characteristics of being a renewable and low polluting material (William *et al*. 2012, Hansen *et al*. 2003, Li *et al*. 2012, Pienkos and Zhang 2009). Woody biomass is considered to be on the first place in the hierarchy of the fuels for the near future (Dhillon and von Wuelhlisch 2013, Eurostat 2011, Thomas and Malczewski 2007). Lignocellulosic biomass is collected from different places (Vilcek 2013, Hansen *et al*. 2013, Kuhlman *et al*. 2013, Omer 2012), starting with the management and exploitation of the forests and ending with the recovered wood from demolition, from cleaning trees in the parks or alleys, or from sorting urban garbage in large cities. The latter category is generically called "urban forest". Biomass can be used as it is or combined with other materials (Zarringhalam *et al*. 2011).

Each technological process produces a lot of wood waste, which is used for own energy purpose, but in some cases the amount of biomass exceeds the own necessities. This is the case, for example, in the pulp and paper industry, where the waste from logs used as raw material results in a large amount of biomass (Gavrilescu 2008), which can be used in various forms:

- as it is, for energy purpose, with a reduced efficiency because of the variable size and moisture content of wood waste;
- as firewood, resulted as waste from the basic sawing of timber, and from the plywood, veneer and chipboard factories;
- as wood machining waste, in the form of chops, briquettes and pellets (Sola and Atis 2012, Stelte et al 2011, Tumuluru *et al*. 2011), used as solid fuels for thermal furnaces and stoves.

Exotic wood species can be found in the hot tropical climate. Today about 50,000 species of tropical trees are known. The exploitation of exotic species has increased by 15% in the developing countries, as stated by Pawlinka and Waliszewska (2011). Harvest time varies from a wood species to another, but it covers generally a period of time between 30 years and 80 years. An amount between 20% and 45% of the harvested wood is used as raw material, the rest being considered as wood waste. Exotic wood species are considered valuable ones, being used as veneers in the art furniture sector and for the interior decorations and panelling. The largest amount of waste from exotic wood species (more than 50% of the waste) can be found at the veneer manufacturers and only a few in the furniture sector. Biomass resulted from the exotic species is poor studied as a potential resource for solid fuels, so far (Grîu 2014).

OBJECTIVES

The objectives of this paper are focused on the investigation of the calorific power of the woody biomass from the exotic wood species, and on the analysis of several calorific characteristics of this raw material, which recommend it as a potential resource of renewable and sustainable energy in the form of solid fuels. The calorific properties of wastes from some exotic wood species were compared with those of the common wood species already used for combustion.

METHOD, MATERIALS AND EQUIPMENTS

Two types of calorific values can be distinguished in case of porous combustible materials with high water content as woody biomass has, and they are higher calorific value (HCV) and lower calorific value (LCV). Because HCV includes also the calorific value of the steam evaporated in the chimney, LCV is the parameter that characterizes the calorific power of the combustible material.

The principle of the determination of the calorific value is to measure the increase of temperature before and after combustion (DIN 51900-1 2000), until the entire heat is released. The calorific value (CV) is determined according to equation 1 (ISO 2009, Grîu 2014, ASTM D3865-12 2000):

$$CV = \frac{k(t_f - t_i) - q_s}{m} [KJ/kg] \quad [MJ/kg] \tag{1}$$

where: k is calorimeter coefficient, expressed in MJ/^{0}C;

t_f, t_i –final and initial temperature, in ^{0}C;

m - mass of sample, in kg;

q_s - sum of heat for wire, cotton and other additives, in MJ.

The system used to determine the calorific value of woody biomass combustion was the explosive calorimeter in oxygen environment, type XRY-1C/Shanghai Changji Geological Instrument Co/China (Fig. 1). It is composed of the calorimeter bomb 3, where a sample weighing about 0.6 - 0.8g is introduced. The calorimeter bomb is placed in the water 4, inside the adiabatic calorimeter equipped with a mantle 5. The water in the calorimeter is mixed with a stirrer 7, and the temperature is measured with the thermoresistance 6. The oxygen is supplied by the tube 1, and the data are displayed on the computer screen 2. Before the test is performed, the calorimeter is calibrated with benzoic acid, having a fixed calorific value of 26,463kJ/kg. Thus the colorimetric coefficient k (Eq. 1) of the installation is determined.

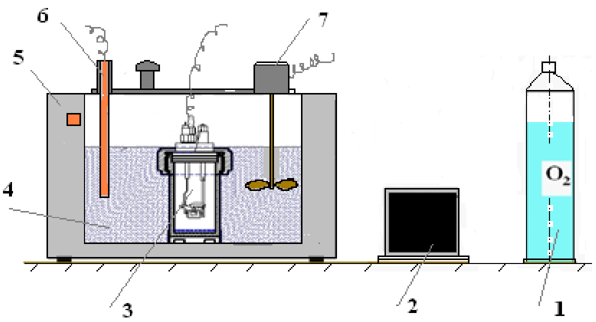


Fig. 1.
System of calorific value determination: 1 - oxygen cylinder; 2 - computer; 3 - bomb; 4 - calorimeter with water; 5 - calorimeter body; 6 - thermoresistance; 7 - stirer.

The woody biomass was taken from several veneer manufacturers. Eleven exotic wood species were tested, namely: Ebanos (*Diospyros ebenum*), African Walnut (*Lovoa trichilioide*), Ayous (*Triplochiton scleroxylon*), Balsa (*Ochroma pyramidale*), Guaiac (*Guaiacum sanctum*), Iroko (*Chlorophora excelsa*), Limba (*Terminalia superba*), Lemon tree (*Chloroxylon swietenia*), Mahagony (*Swietenia mahagoni*), Mansonia (*Mansonia altissima*), Tiama (*Tiama altisima*).

The samples of the test were small fractions of about 0.6-0.8 grams of material, cut from the collected waste, weighed with an accuracy of 0.002g. The samples were fresh cut and clean pieces of exotic wood waste. These samples were placed in a cricible and dried in a laboratory oven at a temperature of 103 ± 2%. The samples were moistured by steaming them in a device, obtaining thus samples with a moisture content of 0%, 10%, 20% and 50% respectively. In the same time, several rectangular parallelepiped samples of 20mm x 20mm x 30mm were cut, in order to determine their density, as a ratio between the mass and their volume.

Other calorific properties were also determined, such as calorific density, speed of combustion (heat release rate) and efficiency of combustion. Calorific density of the analysed wood species was determinated according to equation 2 (Grîu 2014), based on the calorific value (CV) and on the wood density (ρ).

$$CD = CV \cdot \rho \qquad [MJ/m^3] \tag{2}$$

The speed of combustion (SC) was determined as the ratio between the calorific value (CV) and the burning time (t), all multiplied by the mass of the sample (m) (Grîu 2014), according to equation 3:

$$SC = \frac{CV}{t} \cdot m \qquad [KJ/\min] \tag{3}$$

The efficiency of combustion (η) of the fuel with a certain moisture content was determined as the ratio between the calorific value of the sample with a certain moisture content (LCV_{Mc}) and the calorific value of the oven dry sample (CV), according to equation 4 (Grîu 2014):

$$\eta = \frac{LCV_{Mc}}{CV} \cdot 100 \qquad [\%] \tag{4}$$

where: LCV_{Mc} - calorific value of the sample with a certain moisture content, in kJ/kg;
CV - calorific value of the sample with 0% moisture content.

All values obtained by measurements, and the calculated results were processed in Excel™ program, and the necessary graphs were obtained.

RESULTS AND DISCUTION

The calorific value was determined by the computer software. The time and temperatures recorded for each test were also noticed. Calorific value of exotic species was found to be close to the values of European wood species, such as beech wood (*Fagus sylvatica*). The maximum calorific values were recorded for Iroko (21523kJ/kg) and the minimum one for African walnut (18293kJ/kg), as can be seen in Table 1 and Fig. 2.

Table 1

The calorific characteristics of some exotic species

Exotic wood species	Mass, g	Time of combustion, min	Density kg/m^3	$HCV_{10\%}$, kJ/kg	$LCV_{10\%}$, kJ/kg
Abanos (*Diospyros ebenum*)	0.610	25	717	19170	18704
African Walnut (*Lovoa trichilioide*)	0.590	25	728	18756	18293
Ayous (*Triplochiton scleroxylon*)	0.570	29	802	20186	19691
Balsa (*Ochroma pyramidale*)	0.670	36	848	20231	19699
Guaiac (*Guaiacum sanctum*)	0,620	28	784	21480	20972
Iroko (*Chlorophora excelsa*)	0.580	25	716	22061	21523
Limba (*Terminalia superba*)	0.570	32	731	20442	19933
Lemon tree (*Chloroxylon swietenia*)	0.640	27	821	20345	19842
Mahagony (*Swietenia mahagoni*)	0.610	25	590	20073	19601
Mansonia (*Mansonia altissima*	0.590	26	737	19268	18815
Tiama (*Tiama altisima*)	0.620	23	660	19061	18571

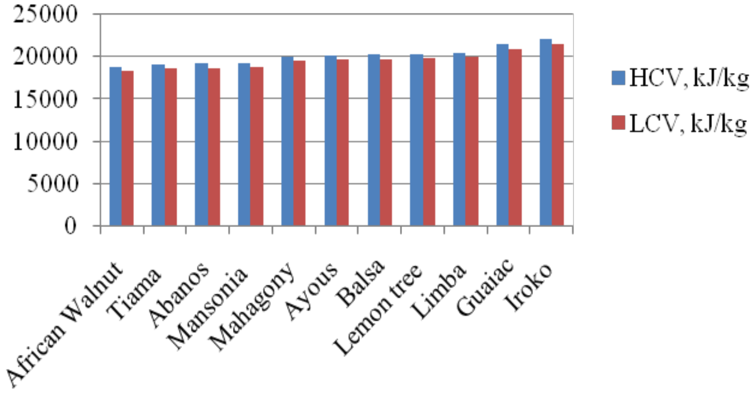
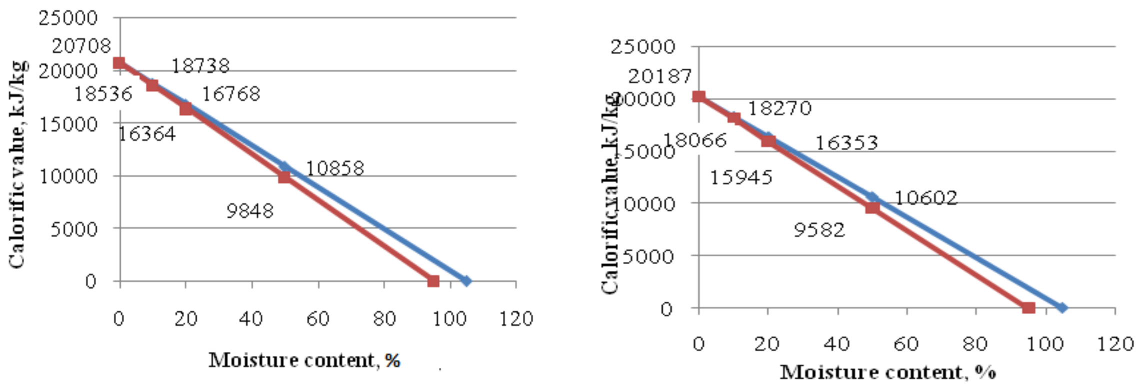


Fig. 2.
Calorific values (HCV and LCV) of the analysed exotic wood species.

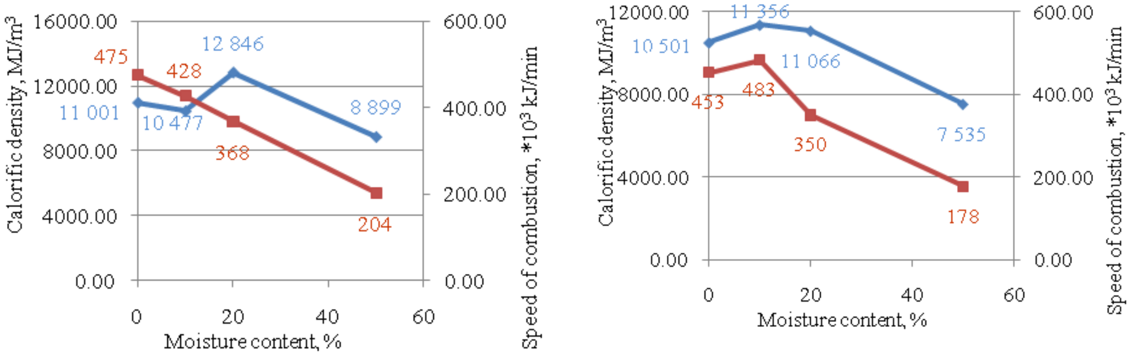
Compared with European hardwood species that recorded calorific values of approx. 18500kJ/kg, in case of exotic wood species, the experimental data have shown higher values (between 18300kJ/kg and 21500kJ/kg). This can be explained by the chemical composition of wood, i.e. chemical composition of exotic species is composed of 65.7% holocellulose and 30.3% lignin, as reported by Pawlinka and Waliszewska (2011) vs. European species with 71% holocellulose and 25% lignin (Kok and Özgür 2013, Obernberger and Thek 2004, Shulga *et al*. 2008). The better results obtained for exotic wood species are explained by their higher lignin content. The obtained values are similar to those of the inferior coal (2200kJ/kg - 24000kJ/kg), or the torrefied pellets (21000kJ/kg - 22000kJ/kg) (Moya and Tenorio 2013, Chen *et al*. 2012, Ohliger *et al*. 2013, Sarvaramini and Larachi 2014, Grîu and Lunguleasa 2014).



Guaiac (*Guaiacum sanctum*) Limba (*Terminalia superba*)

Fig. 3.
Influence of the moisture content upon the calorific value of the exotic wood species.

The moisture content is the most important factor that has influence on the amount of released heat (Nielsen *et al*. 2009). Wood fuel suppliers recommend a moisture content that not exceeds 20% for the firewood and 10%-12% for the other wood products (pellets, briquettes, wood chips, sawdust, etc.). According to the research method, the influence of the moisture content upon the resulted energy was investigated for different moisture contents of 0%, 10%, 20% and 50%, as seen in the diagrams of Fig. 3, where LCV and HCV linear variations are shown. As diagrams show, when the moisture content is between 90% and 110%, the combustion efficiency is zero, because the entire amount of heat is used to remove water from wood. Calorific efficiency, determined by equation 4 was calculated using the different moisture contents of the samples (Table 2). The results are shown in diagrams of Fig. 4 and Fig. 5. As noticed, the maximum calorific values are obtained for a moisture content between 10% and 20%. An increased moisture content decrease the calorific efficiency, whilst a decreased moisture content will increase the drying cost.



Mahagony (*Swietenia mahagoni*) Ebony (*Diospyros ebenum*)

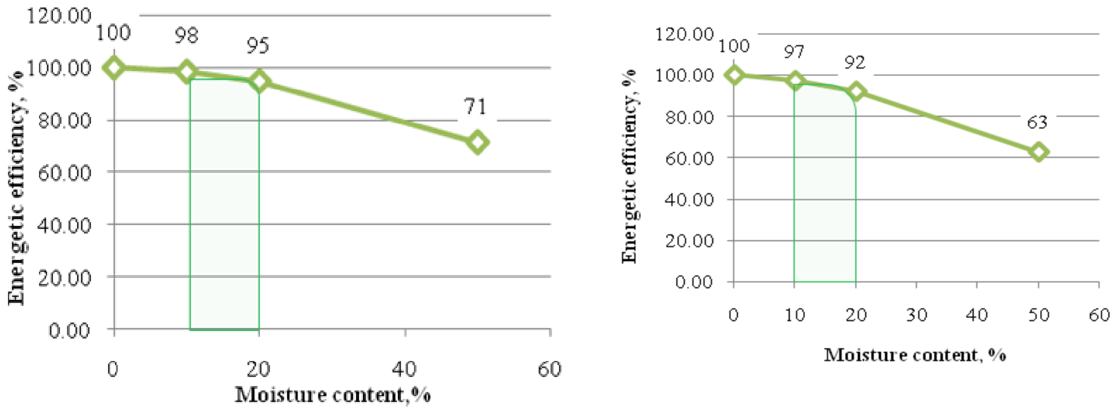
Fig. 4.

Influence of the moisture content upon the calorific density (blue line) and speed of combustion (red line).

Table 2

Some calorific characteristics of exotic species

Specie	m, g	Time of combustion min	MC %	Density kg/m^3	Calorific value, kJ/kg		CD MJ/m^3	SC kJ/min	η_{cm}, %
					HCV	LCV			
Mahagony	0.61	25.5	0	554	20090	20090	11129	0.480	100
	0.64	24.5	10	590	17947	17758	10477	0.463	87
	0.90	32.0	20	819	16057	15680	12841	0.441	78
	1.03	32.0	50	942	10387	9444	8896	0.304	47
Tiama	0.49	23.5	0	445	19085	19085	8492	0.398	100
	0.72	23.0	10	660	17032	16836	11111	0.527	88
	0.95	28.0	20	865	15248	14856	12850	0.504	77
	1.29	32.0	50	1179	9896	8916	10511	0.359	46



Mahagony (*Swietenia mahagoni*) Tiama (*Entandropharma angolense*)

Fig. 5.

Influence of the moisture content upon the calorific efficiency.

Calorific characteristics of exotic species analyzed in this paper are slightly higher as European beech (*Fagus sylvatica*). For example LCV of beech for 10% moisture content is 18,000kJ/kg (Grîu 2014), compared to (18704-21523) kJ/kg in the case of exotic species.

CONCLUSIONS

In wood industry, the waste resulted after processing the exotic wood species can be a potential resource for solid fuels. When this resource is not used for composites, because of its quantity, size and degradability, it can be used as a fuel. The investigations in the paper have shown that the calorific value together with the other calorific characteristics of the exotic species of wood are compared with those of the European species of wood, because of their higher lignin content. Thus, the obtained results presented in the paper, recommend them to be used as biomass for solid fuels.

Through the applied experimental method and because of the obtained results, the paper addresses to the specialists and/or to the traders of biomass and can be a guideline of using biomass resulted from exotic wood species for solid fuels. The authors will continue the research with the determination of the ash content of the analysed species and with the calorific prediction for other exotic species.

REFERENCES

Aghamohammadi N, Suleiman NMN, Aroua MK (2011) Combustion characteristics of biomass in South East Asia. Biomass Bioenerg 35(9):3884-3890.

ASTM D3865-12 (2000) Standard Test Method for Gross Calorific Value of Coal and Coke. American Society for Testing and Materials.

Bhattacharya SC, Abdul P (1989) Low Greenhouse Gas Biomass Option for Cooking in the Developing Countries. Biomass Bioenerg 22(4):305-307.

Boutin JP, Gervasoni G, Help R, Seyboth K, Lamers P Ratton M (2007) Alternative Energy Sources in Transition Countries. The Case of Bio-energy in Ukraine. Environ Eng Manag J 6(1):3-11.

Chen WH, Song-Ching Y, Herng-Kuang S (2012) Hydrothermal carbonization of sugarcane bagasse via wet torrefaction in association with microwave heating. Bioresource Technol 118:195-203.

DIN 51900-1 (2000) Determining the gross calorific value of solid and liquid fuels using the bomb calorimeter, and calculation of net calorific value – Part 1. General information. German Institute for Standardization.

Demirbas A, Demirbas AS (2004) Briquetting Properties of Biomass Waste Materials. Energ Source Part A 26(1):83-91.

Dhillon RS, von Wuelhlisch G (2013) Mitigation of Global Warming through Renewable Biomass. Biomass Bioenerg 48:75-87.

Eurostat (2011) Forestry in the EU and the World. A Statistical Portrait. 2011 edition. Available from: http://epp.eurostat.ec.europa.eu/cache/ity_offpub/ks-31-11-137/en/ks-31-11-137-en.pdf.

Gavrilescu D (2008) Energy from Biomass in Pulp and Paper Mills. Environ Eng Manag J 7(5):537-546.

Grîu T, Lunguleasa A (2014) Torrefaction of Beech and Spruce Sawdust. PRO LIGNO 10(2):40-45.

Grîu (Dobrev) T (2014) Evaluarea si cresterea puterii calorice a biomasei (Appreciation and increasing of biomass calorific value) Doctoral Thesis. Transilvania University of Brasov.

ISO 1928 (2009) Solid Mineral Fuels. Determining the Gross Calorific Power by Calorimeter Bomb and Calculus of Net Calorific Power. International Standardisation Institute, New York.

Jehlickova B, Morris R (2007) Effectiveness of Policy Instruments for Supporting the Use of Waste Wood as a Renewable Energy Resource in the Czech Republic. Energ Policy 35(1):577-85.

Hansen MAT, Jørgensen H, Laursen KH, Schjoerring JK, Felby C (2013) Structural and Chemical Analysis of Process Residue from Biochemical Conversion of Wheat Straw (*Triticum aestivum* L.) to ethanol. Biomass Bioenerg 56:572-581.

Kok MV, Özgür E (2013) Thermal analysis and kinetics of biomass samples. Fuel Process Technol 106:739–743.

Kuhlman T, Diogo V, Koomen E (2013) Exploring the Potential of Reed as a Bioenergy Crop in the Netherlands. Biomass Bioenerg 55:41-52.

Li J, Yang W, Blasiak W, Ponzio A (2012) Volumetric combustion of biomass for CO_2 and NO_x reduction in coal-fired boilers. Fuel 102:624-633.

Lundborg A (1998) A Sustainable Forest Fuel System in Sweden. Biomass Bioenerg 15(4-5):399-406.

Moya R, Tenorio C (2013) Fuel wood characteristics and its relation with extractives and chemical properties of ten fast-growth Species in Costa Rica. Biomass Bioenerg 56:14-21.

Nielsen NPK, Gardner DJ, Poulsen T, Felby C (2009) Importance of Temperature, Moisture Content and Species for the Conversion Process of Wood Residues into Fuel Pellets. Wood Fiber Sci 41(4):414–425.

Obernberger I, Thek G. (2004) Physical Characterisation and Chemical Composition of Densified Biomass Fuels with Regard to their Combustion Behavior. Biomass Bioenerg 27(6):653–669.

Ohliger A, Forster M, Kneer R (2013) Torrefaction of beechwood: A parametric study including heat of reaction and grindability. Fuel 104:607-613.

Omer AM (2012) Biomass energy resources utilization and waste management. Agricultural Sciences 3(1):124-45. DOI: http://dx.doi.org/10.4236/as.2012.31016.

Okello C, Pindozzi S, Faugno S, Boccia L (2013) Bioenergy Potential of Agricultural and Forest Residues in Uganda. Biomass Bioenerg 56:515-525.

Pawlicka A, Waliszewska B (2011) Chemical composition of selected species of exotic wood derived from the region of Africa. Acta Scientiarum Polonorum- Silvarum Colendarum Ratio et Industria Lignaria 10(1):37-41.

Pienkos TP, Zhang M (2009) Role of pretreatment and conditioning processes on toxicity of lignocellulosic biomass hydrolysates. Cellulose 16(4):743–762.

Prasertsan S, Sajakulnukit B (2006) Biomass and Bioenergy in Thailand: Potential, Opportunity and Barriers. Renew Energ 31(5):599-610.

Profft I, Mund M, Weber GE, Weller E, Schulze ED (2009) Forest management and carbon sequestration in wood products. Eur J Forest Res 128(4):399–413.

Sarvaramini A, Larachi F (2014) Integrated biomass torrefaction – Chemical looping combustion as a method to recover torrefaction volatiles energy. Fuel 116:158–167.

Shulga G, Betkers T, Brovkina J, Aniskevicha O, Ozolinš J (2008) Relationship between Composition of the Lignin-based Interpolymer Complex and its Structuring Ability. Environ Eng Manag J 7(4):397-400.

Sola OC, Atis CD (2012) The Effects of Pyrite Ash on the Compressive Strength Properties of Briquettes. KSCE Journal of Civil Engineering 16(7):1225-1229.

Stelte W, Holm JK, Sanadi AR, Barsberg S, Ahrenfeldt J, Henriksen UB (2011) A Study of Bonding and Failure Mechanisms in Fuel Pellets from Different Biomass Resources. Biomass Bioenerg 35(2):910-918.

Tumuluru JS, Wright CT, Hess JR, Kenney KL (2011) A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. Biofuels Bioprod Bioref 5(6):683–707.

Thomas SC, Malczewski G (2007) Wood Carbon Content of Tree Species in Eastern China: Interspecific Variability and the Importance of the Volatile Fraction. J Environ Manag 85(3):659–662.

Vamvuka D (2011) Bio-oil, solid and gaseous biofuels from biomass pyrolysis processes – An overview. Int J Energ Res 35(10):835-862.

Verna VK, Bram S, de Ruyck J (2009) Small Scale Biomass Systems: Standards, Quality, Labeling and Market Driving Factors – An Outlook. Biomass Bioenerg 33(10):1393-1402.

Vilcek J (2013) Bioenergetic potential of agricultural soils in Slovakia. Biomass Bioenerg 56:53-61.

Zarringhalam MA, Gholipour ZN, Dorosti S, Vaez M (2011) Physical properties of solid fuel briquettes from bituminous coal waste and biomass, Journal of Coal Science and Engineering (China) 17(4):434-438.

William A, Jones JM, Ma L, Pourkashanian M (2012) Pollutants from the combustion of solid biomass fuels. Prog Energ Combust 38(2):113-137.