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PROPERTIES AND USE OF BIOMASS FROM RECLAIMED LAND IN THE NORTH BOHEMIAN BASIN

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ABSTRACT

Spoil heaps are negative urban landscape features resulting from intense human activities to acquire mineral resources. One very positive method for reclaiming spoil heaps is afforestation. This paper analyzes the quality of Black locust wood acquired from the reclaimed area of Varvažov, North Bohemian Basin, Czech Republic. The following characteristics were used as indicators of the quality of wood obtained from the given area: chip dimensions; ash content; bulk density; bark content; contents of C, H, N, and O; and contents of S, P, Ca, Mg, K, Fe, Zn, and Mn. Black locust biomass is suitable for energy purpose, although it contains an increased proportion of inorganic elements. The other properties, such content of C, H, N, and O, ash content as well as heating value, are in compliance with the standardized values. The Black locust chips can be categorized as Coarse-grained energetic wood chips with minimal dust particle content according to particle-size distribution analysis.

KEYWORDS: Spoil heaps, biomass, reclaimed land, energy purpose, Black locust.

INTRODUCTION

The primary importance of afforested anthropically disturbed areas is nonproductive. Tree communities on artificial anthropogenic soils fulfil landscaping, environmental, hygienic, soil-protection, water-management, and aesthetic functions as well as all other nonproductive functions connected to forest communities.

Surface mining was initiated in the Ústí nad Labem region in 1895 with the Gustav I mine in Varvažov. In 1949, the Gustav II mine was opened and became one of the first mines to include modern machine mining in connection with long-distance conveyor transport. Purposeful reclamation was carried out from 1930 and ended in 1960. A slowdown phase with subsequent liquidation of the mine began on January 1994.

The biological importance of areas affected by mineral resource extraction has now become widely recognized among the expert public. Although lignite extraction was, is, and will continue to be one of the most important energy sources for the national economy, this activity also is connected with negative environmental impacts that lead to transforming the character of the landscape, creation of artificial areas formed by human activities, and formation of spoil heaps. It should not surprise that spoil heaps can serve as refugia for numerous plant and animal species retreating from the "normal" landscape (Zeleznik and Skousen 1996; Vojar et al. 2012). Although it is by no means apriority function of these locations, their productive function is not negligible and it is important to take into consideration their specific characteristics. In addition, these areas are important from the landscape point of view in the Czech Republic analogous to silvopasture systems as described by Surová et al. (2014).

Among potential highly negative factors in spoil heaps are these soils'poor physical states, usually associated with unfavorable water retention (weak sponge effect) in these soils (Slávik and Dimitrovský 2006). This is thereas on sufficient precipitation, and particularly during the vegetation period, is the main criterion for good, or at least satisfactory, tree growth in these areas (Bažant 2010). Afforestation of overlying spoil soils is a process with initially extreme soil and microclimatic requirements for tree development. The emergent forest stands in these locations are therefore classified by law into the group of protected forests or special purpose forests where the productive function is not a priority. Success in establishing forest stands on spoil heaps depends primarily on the pedological properties of the spoil soils used for reclamation, technologies used to correct deficient soil properties, selection of suitable tree species for individual spoil soils, afforestation method, spatial organization of planting, planting density, quality of afforesting material, and subsequent treatment and protection of cultures against biotic pests (Čermák and Kohel 2003). The soil properties of most spoil heaps are created by clays of various mineral compositions with high proportions of illite and kaolinite as the basic substances forming the heaps' cores. Reclamation success further depends on the soil's physical properties, structure, and particle size.

Dendromass is a type of biomass, consisting of wood or of lignified plant matter from forestry, agriculture, wood processing industry or from other sources, which can be used to produce energy. If it is desired to use biomass from reclaimed areas for energetic purposes, it is necessary to determine those of the wood's energy parameters that affect the combustion process (Pastorek et al. 2004; Nussbaumer 2003; Shao et al. 2012). Biomass includes a volatile matter in the form of carbon, hydrogen and their compounds with oxygen. Compared to fossil fuels (coal, petroleum, natural gas), biomass differ higher water content and lower energy density (energy content per unit mass). In comparison with solid fossil fuels, biomass has lower density and the proportion of incombustible impurities (Trenčiansky et al. 2007). The basic parameters of biomass quality are C, H, N, S and O content. These elements form the combustibles (chemically bound energy) and determine the heating value of biomass (El Bassam 1998). The great advantage of biomass is negligible sulfur content. The chemical composition of different types of biomass is similar; therefore the heating value for the same moisture for various tree species varies only slightly. Chip diameter is an important monitored parameter which determines the combustion technology. Chip moisture content affects the heating value. Ash content affects biomass quality, play an important role in combustion efficiency and further can be used to calculate ash production (Fryda et al. 2010; Shao et al. 2012). Ash from burned wood is a suitable fertilizer that can be used in reclamations, where as part of so-called biological reclamation sufficient nutrients must be provided for the reclaimed area's initial growth phase (Štýs et al. 1981; Olanders and Steenari 1995). Water and ash content comprise so-called ballast substances that can diminish the fuel's value. Bark content is an indicator influencing ash content because bark is a main source of fly emissions.

This work included the determining of basic properties of biomass (heating value, ash content, bulk density, bark content, content of C, H, N elements etc.) obtained of Black locust wood grown at reclaimed land after lignite mining. The basic objective is to determine whether the black locust biomass suitable for energy purposes according to appropriate standards.

MATERIAL AND METHODS

Materials

Experiments were performed on 60-years-old black locust (*Robinia pseudoacacia* L.) trees from former lignite mining site at Varvažov (at the former Gustav mine), part of municipality Telnice in the Ústí nad Labem Region of the Czech Republic. The location is slightly banked, with southeast exposure and altitude of 280 meters above mean sea level. Stand soil is clayey-loam.

Fig 1: Location of Varvažov, Czech Republic.

Methods

Chips were produced 3 days after collection using a wood chipper TP 160 PTO (Linddana, Denmark). Samples contained a high proportion of branches and the upper parts of trees. Chip samples were stored in two layers in strong plastic bags and marked with a sample number as well as name. First, the moisture content of samples was determined. Then the chips were prepared for analysis.

Evaluation and calculation

Determining chip dimensions

The particle sizes of energy chips were analyzed according to EN 15149-1 (2010) by sifting the chips for 5 min through a set of sieves with mesh sizes of 50, 35, 10, 5, 1, and 0.5 mm and a bottom in an automatic vibratory sieve shaker AS 200 (RETSCH, Germany). Sifted fractions' masses were determined with accuracy of 0.001 g. Samples from each sieve were then weighed.

Determining moisture content

Samples were inserted into a laboratory dryer ED, APT Line II (Binder; Germany) and dried at 103 ± 2°C to a constant weight.

Relative moisture content of wood chip samples was calculated according to EN 14774-2 (2009),

$$w_r = \frac{m_w - m_0}{m_w} * 100 \tag{1}$$

where: w_r - the relative moisture content of the samples (%),
m_w - the mass of the sample at a certain moisture w (kg),
m_0 - the mass of the oven-dry sample (kg).

Determining ash content

Wood chip samples were prepared weighing approximately 10 grams per sample. The samples needed to be in an absolutely dry state. Samples were inserted into annealing dishes and then weighed with the dish. Annealing dishes were inserted into an LMH 04/12 (LAC, Czech Republic) muffle furnace. Temperature in the furnace was increased at an even rate over 60 min to 500°C and kept at this temperature for a further 30 min. Annealing then continued for 60 min to 815°C ±10°C, this temperature was maintained for 360 min. Then, annealing dishes were collected from the furnace and gradually cooled. After cooling, annealing dishes were weighed with a precision of 0.001 mg.

Ash content of the samples was expressed as a percentage and calculated according to ISO 1171 (2011):

$$A_d = \frac{m_a}{m_L} = \frac{m_3 - m_1}{m_2 - m_1} * 100 \tag{2}$$

where: A_d - the ash content (%),
m_a - the mass of the ash (g),
m_L - the mass of the chip sample (g),
m_3 - the mass of the sample jar with ash (g),
m_1- the mass of the empty sample jar (g),
m_2 - the mass of the sample jar with chips (g).

Determining bark content

Ca 200 g of chips was weighed into the sample. Bark was separated from the analyzed samples. The sample jar with chips and without bark was then weighed. Lastly, the sample of separated bark was weighed with the sample jar. All weightings were carried out with a precision of 0.01 g.

Bark content in the analyzed chip sample was calculated according to STN 48 0058 (2004),

$$X_b = \frac{m_b}{m_c} * 100 \tag{3}$$

where: X_b - the bark content in chip sample (%),
m_b - the mass of the bark (g),
m_c - the mass of the chips (g).

Determining bulk density

Five samples needed to be prepared to determine bulk density. First, the mass of an empty container (m_1) was determined. Chip samples were poured into the container from a height of 200–300 mm. The filled container needed to be struck twice so as to cause free chip particles to settle. This was done by dropping the container from a height of 150 mm onto a wooden board. Excess material at the top of the container was removed. Then, the mass of the full container (m_2) was determined. All weightings were carried out with a precision of 0.01 g.

Bulk density was calculated according to EN 15103 (2009),

$$m_{bd} = \frac{m_2 - m_1}{V} \tag{4}$$

where: m_{bd} - the bulk density (kg.m^{-3}),
m_1 - the mass of the empty container (kg),
m_2 - the mass of the full container (kg),
V - the volume of sample container (m^3).

Determining content of C, H, and N and recalculation of O

This analysis was based on measuring the elements N, C, and Sin the gas formed by biofuel combustion in pure oxygen and their subsequent determination in a chromatographic column. The proportions of carbon (C_{daf}), hydrogen (H_{daf}), and nitrogen (N_{daf}) in wood and bark samples were determined using a NCS-FLASH EA 1112 analyzer (Thermo Scientific, USA) according to EN 15407 (2011).

The proportion of oxygen in the samples was calculated under the assumption of zero sulfur content in biomass ($S_{daf} = 0$) in accordance with EN 15296 (2011),

$$O_{daf} = 100 - C_{daf} - H_{daf} - N_{daf} \tag{5}$$

where: O_{daf} - the proportion of oxygen in volatile matter (%),
C_{daf} - the proportion of carbon in volatile matter (%),
H_{daf} - the proportion of hydrogen in volatile matter (%),
N_{daf} - the proportion of nitrogen in volatile matter (%).

Determining total content of C, H, and N was carried out according to EN 15104 (2011). Samples were burned in oxygen such that ash and gas combustion products were formed. Combustion products were processed so as to ensure that no combustion products of hydrogen combined with sulfur or halogens were released with water vapor. Nitrogen oxide was reduced to elemental nitrogen. carbon dioxide, water vapor, and nitrogen were then quantitatively analyzed from the gas flow using a NCS-FLASH EA 1112 analyzer (Thermo Scientific, USA) according to EN 15407 (2011).

Determining of heating value

The heating value of Black locust biomass was calculated according to Perelygin (1965) and Dzurenda (2005),

$$Q_d = \left[339 * C_{daf} + 1029.7 * H_{daf} - 108.8 * O_{daf}\right] * \left[\frac{100 - A_d - w_r}{100}\right] - w_r * 25.1 \tag{6}$$

where: Q_d - the heating value (MJ.kg^{-1}),
O_{daf} - the proportion of oxygen in volatile matter (kg.kg^{-1}),
C_{daf} - the proportion of carbon in volatile matter (kg.kg^{-1}),
H_{daf} - the proportion of hydrogen in volatile matter (kg.kg^{-1}),
A_d - the ash content (%),
w_r - the relative moisture content of the samples (%),
N_{daf} - the proportion of nitrogen in volatile matter (kg.kg^{-1}),

Determining S, P, Ca, Mg, K, Fe, Zn, and Mn content

The chip samples were fragmented into fine particles using a cutting mill PULVERISETTE 19 (Fritsch, Germany). The samples were then mineralized in a microwave furnace MARS 5 (CEM, USA) using closed pressurized digestion.

Inductively coupled plasma optical emission spectrometer ICP-OES 730-ES (Varian Inc., USA) was used to determine the content of elements and significant concentrations of individual elements in analyzed samples according to ISO 11885 (2007), EN 15290 (2011) and EN 15297 (2011). A pump delivers samples to a nebulizer which transforms the originally liquid sample into a fine mist (solution droplets) that is carried by a stream of argon to a plasma flame. An alternating high-frequency magnetic field keeps the argon plasma at 6.000–10.000 K. Under such conditions, the solvent immediately vaporizes and the chemical bonds break in the molecules of those compounds present.

RESULTS AND DISCUSSION

In general, Black locust belongs among favorite tree species for its growth modesty and ability to quickly grow on soils damaged by human activity. In some countries (e.g. Germany, USA), the Black locust belongs among main tree species on land reclamation after coal mining (Zeleznik and Skousen 1996; Böhm et al. 2011). Furthermore, Black locust wood is suitable for biomass, because due to its higher density reaches a high heating value.

Our results were compared primarily with EN 14961-1 (2010) (Tabs. 1 and 4). This standard defines and specifies the quality of solid biofuels, i.e. solid biofuels, which are produced as final products of forest production, as well as logging residues or waste from woodworking industry. Classification to the appropriate group and compared with average values, it is important to use these commodities for bioenergy production.

Particle-size analysis of our Black locust chips (Tab. 1) indicates that this chips may be categorized as Coarse-grained energetic wood chips according to EN 14691-1 (2010).

Tab. 1: Particle-size distribution of wood chips.

	Sieve size (mm)	Mean (%)
Coarse	50	2.47
	45	4.21
Main	10	55.37
	5	31.75
Fine	<5	6.19
Total		100.0

In general, a wood chip in a dry state has a good heating value, which can be compared to the lignite. For this reason, our wood chip conforms with EN 14961-1 (2010) as class P16B (Fig. 2 and Tab. 2), with basic properties as: Fraction (dimensions) up to 4.5 cm, moisture content up to 50 %, ash content up to 3 % as well as minimum heating value 8–10 MJ.kg^{-1} (Tab. 3). Higher dust particle content in chips causes problems in combustion (even explosiveness of biofuel).

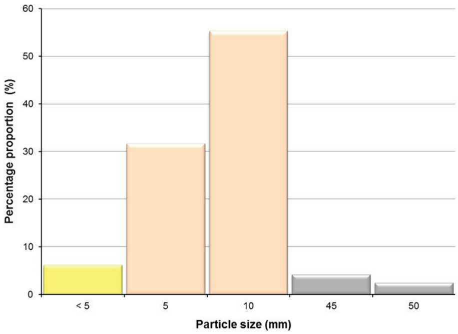

Fig. 2: Average percentage proportion of particles.

Tab. 2: Standardized wood chips properties.

Class	Main fraction, minimum 75 %, w-%, (mm)	Fine fraction w (%)	Coarse fraction w (%)
P16A	3.15<P<16 mm	<12 %	<3 %>16 and all < 31.5 mm
P16B	3.15<P<16 mm	<12 %	< 3 % > 45 mm and all < 120 mm
P45A	8<P<45 mm	<8 %	< 6 % > 63 mm, and maximum 3.5 %>100 mm, all < 120 mm
P45B	8<P<45 mm	<8 %	< 6 % > 63 mm, and maximum 3.5 %>100 mm, all < 350 mm
P63	8<P<63 mm	<6 %	< 6 % > 100 mm and all < 350 mm
P100	16<P<100 mm	<4 %	< 6 % > 200 mm and all < 350 mm

Our results of heating values for black locust biomass correspond to EN 14961-1 (2010). Similar values were found by Geyer and Walawender (1994), as well as Kraszkiewicz (2013) while Stringer and Carpenter (1986), Klašnja et al. (2013) and Brenes (2006) stated higher heating values for black locust. On the other hand, Gruenewald et al. (2007), who investigated Black locust wood from reclaimed Lusatia and Helmstedt mining sites in Germany, found a slightly lower heating value. The heating values for the various researches are given in Tab. 3.

Although the standard EN 14961-1(2010) reports the mode value 5 % for the ash content (Tab. 4), generally, the ash content reaches a value up to 1 %. This fact was also confirmed by Klašnja et al. (2013).Other authors, such as Kopitović et al. (1989), Fengel and Wegener (1984), and So et al. (1983), found even lower values of ash content (Tab. 3). Adamopoulos et al. (2005) found that the ash content increased from the bottom to the top of the stems, i.e. the lowest values were found for the bottom parts (0.36 %), while the upper parts reached the highest values (0.76 %). In general, variability of properties differs within an individual tree, both vertically along the stem and horizontally at cross-section of stem (Bošeľa et al. 2014).

Tab. 3: Comparison of Black locust heating values and ash content.

Heating values (MJ.kg^{-1})							
Our results	**Gruenewald et al. (2007)**	**Geyer and Walawender (1994)**	**Kraszkiewicz (2013)**	**Brenes (2006)**	**Stringer and Carpenter (1986)**	**Klašnja et al. (2013)**	**EN 14961-1 (2010)**
18.18**	16.54**	18.86*	17.82*	21.7*	19.85*	21.19*	18.70*

Ash content (%)						
Our results	**Gruenewald et al. (2007)**	**Kopitović et al. (2013)**	**Fengel and Wegener (1984)**	**So et al. (1980)**	**Klašnja et al. (2013)**	**EN 14961-1 (2010)**
0.89**	1.50**	0.23*	0.30*	0.31*	0.77*	5.0*

*results from unmined areas

** results from post-mining reclaimed areas.

The moisture content of the mixed chips was 36.60 %. That is close to a value technologically usable for energy purpose. The moisture content of the wood chips was 31.61 %. This value is lower than that for the mixed chips. Moisture content of bark was much higher (52.3 %), what also has implications for the higher moisture content of mixed chips.

Tab. 4 shows the content of basic organic and inorganic elements of Black locust wood. In all cases, the contents of organic elements (*C, O, H, N*, and *S*) were close to the values listed in EN 14961-1 (2010). For example, carbon content corresponds not only with the EN 14961-1 (2010) but also with Ciuvăț et al. (2013) as well as Li et al. (2013). On other hand, the contents of inorganic elements were greater than stated in EN 14961-1 (2010). Several times higher values were found for magnesium (*Mg*), calcium (*Ca*), potassium (*K*), phosphorus (*P*) and iron (*Fe*). Bungart and Hüttl (2001) found greater differences in values of inorganic elements. They investigated poplar, willow and aspen biomass from reclaimed post-mining area of the Lusatian lignite region in Germany. For example, they found much greater content of nitrogen (4.9 mg.g^{-1}), and sulfur (0.3 mg.g^{-1}) in comparison with our results. In another study, the authors Bungart and Hüttl (2004) states even several times higher values of nitrogen, calcium and potassium for the poplar wood from the different post-lignite mining sites. On the other hand, our results of potassium, magnesium, calcium and phosphorus were much greater than their values. These differences depend on tree stands and they are strongly associated with soil conditions of growth. Soil closest to the remains of lignite is the most affected and it mainly consists of a large proportion of carbon and nitrogen (Panagopoulos 2013). Towards the surface, that proportion decreases significantly. It is essential to know the type and age of trees growing on this site because it directly affects the amount of individual elements in their wood.

Tab. 4: Comparison of Black locust biomass properties with standardized values.

	Monitored characteristics	Our results		Standardized values EN 14961-1 (2010)	
		Average value	**Range**	**Mode value**	**Modal range**
Normative	Dimensions (mm)*	P 16B	-	-	3.15 – 100
	Heating value Q_d (MJ.kg^{-1}) (dry-matter)	18.18(0.3)	-	18.7	18.3 – 18.5
	Moisture content w_r (%), wood + bark	36.60 (0.4)	35.34 – 27.88	-	10 – 55
	Moisture content w_r (%), wood	31.61(1.41)	30.42 – 32.45	-	-
	Moisture content w_r (%), bark	52.30 (3.25)	49.56 – 54.30	-	-
	Ash content A_d (%), bark	4.32 (1.35)	4.13 – 4.51	-	-
	Ash content A_d (%), wood	0.31 (0.03)	0.304 – 0.313	-	-
	Ash content A_d (%), wood + bark	0.89 (0.82)	0.84 – 0.91	5	2 –10
Informative	Bulk density m_{bd}(kg.m^{-3})	353.28 (6.17)	337.3 – 361.3	-	225 – 380
	Bark content X_b (%)	14.34 (5.95)	13.55 – 19.30	30	3 – 30
	Carbon C (%)	49.28 (8.0)	-	51	50 – 51
	Nitrogen N (%)	1.15 (8.1)	-	0.5	0.3 – 0.8
	Hydrogen H (%)	5.93 (8.0)	-	6	5.6 – 6.1
	Oxygen O (%)	43.59 (2.0)	-	40	40 – 43
	Sulfur S (%)	0.05 (8.0)	-	0.04	0.01 – 0.08
	Calcium Ca (g)**	157.36(10.9)	-	4	3 - 5
	Magnesium Mg (g)**	29.38 (6.2)	-	0.25	0.1 – 0.4
	Potassium K (g)**	197.02 (8.3)	-	1.5	1 – 1.4
	Phosphorus P (g)**	27.21 (8.9)	-	0.3	0.03 - 1
	Zinc Zn (g)**	0.45 (14.7)	-	0.05	0.02 – 0.1
	Manganese Mn (g)**	1.33 (8.8)	-	0.12	0.01 – 0.8
	Iron Fe (g)**	4.95 (16.3)	-	0.15	0.1 – 1.5

*see Tab. 8
**the element weight (g) in relationto theweight (kg)of dry matter
Values in parentheses represent±SD.

CONCLUSIONS

All organic elements were in accordance with standard. Hydrogen and sulfur contents contributed favorably to the heating value. The remaining elements, primarily oxygen and nitrogen and to a lesser extent carbon, caused lower heating value of biomass. Biomass contained very high proportions of the main nutrients (inorganic elements). Trace element contents were substantially higher than is usual; this is probably due to the type of soil. The resulting ash should be used as fertilizer because of positive impact of high phosphorus, potassium, calcium and magnesium content. The bark content indicates that the examined samples can be used for energetic purpose. The bark content in the monitored samples ensures that the fly ash will be minimal, thereby increasing the value of biomass. Ash content was below 5 % in all cases. The determined ash content in samples of wood + bark (0.89 %) is very favorable in terms of biomass quality even despite the high contents of trace elements in the samples. The analysis clearly indicated the higher moisture content for bark (52.3 %) than for wood (31.61 %) as well as wood and bark (36.61 %). The produced chips can be categorized as Coarse-grained energetic wood chips with minimal dust particle content according to particle-size distribution analysis.

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