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ASSESSMENT OF HEAVY METALS LEACHING FROM (BIO)CHAR OBTAINED FROM INDUSTRIAL SEWAGE SLUDGE

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Abstract. Biochar can be produced from many various feedstock including biomass residues such as straw, branches, sawdust and other agricultural and forestry waste. One of the alternatives is to obtain biochar from industrial sewage sludge, however, the use of such a product could be limited due to high quantities of heavy metals in the biochar as a product. Total concentration of heavy metals provides only limited information on the behavior of heavy metals, therefore, batch leaching and up-flow percolation leaching tests were applied to study the leaching of heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) from (bio)char produced from two types of sewage sludge: from paper mill and leather industries.

Keywords: biochar, leaching test, pyrolysis, heavy metals.

Introduction

According to European Biochar Certificate (Schmidt *et al.* 2014) biochar "is a heterogeneous substance rich in aromatic carbon and minerals. It is produced by pyrolysis of sustainably obtained biomass under controlled conditions with clean technology and is used for any purpose that does not involve its rapid mineralization to CO_2 and may eventually become a soil amendment" (Schmidt *et al.* 2013). Definition 'biochar' will be used in general meaning, '(bio) char' – analyzed biochar produced from industrial sewage sludge, which contains heavy metal.

The pyrolysis uses biomass from a wide variety of biomass residues such as straw, branches, sawdust and other agricultural and forestry waste as raw material, even algal (Bird *et al.* 2011). Some of the various waste materials that potentially can be used as feedstock for biochar production include sewage sludge, animal manure, compost, and industrial or landfill waste (Navia, Crowley 2010; International Biochar… 2013).

Sewage sludge produced during wastewater treatment are some of the most difficult waste materials to manage due to the increasing quantities produced and the pathogenic organisms and metal contents present in the sludge (Bamforth *et al.* 2004). For instance, in the EU the produced sewage sludge has recently been estimated at 10.13 million tons (on the dry basis) (Agrafioti *et al.* 2013).

Producing (bio)char from sludge is important to know that industry wastewaters and the sludge are known to contain a variety of heavy metals (Cd, Pb, Cr, Ni, Zn, Cu), which can leach out and contaminate soils as well as surface and ground water sources (Çelebi, Kendir 2002).

The main heavy metals of concern in sewage sludge are Cd, Zn, Cu, Pb, Se, Mo, Hg, Cr, As, and Ni. The most bioavailable sludge-borne metal is Zn, followed by Cd and Ni, Cr and Pb uptake by plants was observed to be insignificant (Bradl 2005; Hossain *et al.* 2011). However (bio)char is able to very effectively bind a number of heavy metals. For these reasons it is very important to analyze potential pollution by heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) caused by industrial sewage sludge on environment, especially for soil and groundwater.

Two types of leaching tests methods were used in this work: LST CEN/TS 14405 and LST EN 12457-3.

Methods are applicable to determine the leaching behaviour of inorganic constituents from waste, produced eluate can be characterized physically and chemically. Also it let to know liquid/solid (L/S) ratios, leachate composition, factors controlling leachability such as pH, redox potential and physical parameters.

According to European Biochar Certificate (Schmidt *et al.* 2014), important biochar physico-chemical properties are: biochar yield, pH value, ash content, moisture content, total organic carbon content C, %, bulk density), heavy metals concentration, which effect (bio)char feature to retain heavy metals. These properties are considered to have the greatest effect on the physical properties of the biochar (Mukome *et al.* 2013; Thomsen *et al.* 2011, Agrafioti *et al.* 2013).

The aim of this work was to evaluate physico-chemical properties of the biochar as well as the leaching behavior of heavy metals from biochar, produced from two types of sewage sludge under 450 °C and 600 °C.

Materials and methods

Sampling of the feedstock for biochar production

For biochar production, two types of sewage sludge were selected for sampling: from paper mill company and leather company. Companies were taken due relatively large heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) composition in sewage sludge (European Communities 2001). Heavy metals in paper mill sewage sludge occur during paper production additional steps, such as de-inking and bleaching, it generates deinking sludge, containing dyeing agents and chemicals; leather sewage sludge contains heavy metals originating from the reactive products used during the tanning process.

The sludge samples were taken on 28th of February, 2014, at +4 – 0 °C temperature. Industrial sewage sludge was sampled based on LST EN ISO 5667-13. About 10 kg of each type industrial sludge was taken and mixed. Sludge was dewatered and collected recently after manufacturing process in both companies. Sludge was collected with gloves and stored in bags till sludge drying and biochar production (Pavojingų medžiagų… 2011).

(Bio)char production

For (bio)char production the sewage sludge samples were dried. Both types of dewatered sludge were dried in oven at 105 °C for 1 hour according to the sample preparation protocol described by Agrafioti *et al.* (2013); Ruiz Celma *et al.* (2012); Dacera and Babel (2013). Dried sludge was stored in airtight plastic bags (Agrafioti *et al.* 2013).

Before (bio)char production, the sludge samples were weighted by electronic balance (with resolution of 0.01 g) in order to calculate (bio)char yield after (bio)char production. The dried feedstock of sewage sludge was separately shrink-wrapped into aluminum foil (Saleh *et al.* 2012; Komkienė, Baltrėnaitė 2014) and put into different diameter porcelain crucibles and transferred into muffle furnace E5CK–T and pyrolyzed under limited O_2 conditions at two different thermal procedures: a) 450±5 °C. The heating rate of the furnace was fixed at about 10 °C/min and the heating was carried out until the temperature reached 450 °C. Entire pyrolysis procedure took 2 hours to complete, because according to Lu *et al.* (2013) 2 h is the most appropriate time for carbonization; (b) 600±5 °C. The heating rate of the furnace was fixed at about 10 °C/min and the heating was carried out until the temperature reach 600 °C. Residence time was 2 hours including heating rate (Méndez *et al.* 2013). After pyrolysis process, (bio)char samples were moved to fume hood and cooled at ambient temperature (20±3 °C). Then produced (bio)char of each type of sewage were weighted in order to calculate (bio)char yield and stored in plastic bags.

Physical-chemical properties of the sludge

(Bio)char yield (BY) was determined as the ratio of the weight sample before and after heat treatment as follows (Agrafioti *et al.* 2012; Méndeza *et al.* 2013):

$$BY=\frac{W_2}{W_1}\cdot 100,\ \%, \qquad (1)$$

where: W_1 – the dry weight of a sample prior to pyrolysis, g; W_2 – the weight of a pyrolized sample, g.

(Bio)char pH was determined by an instrumental method using a glass electrode in a 1:5 (volume fraction) suspension of (bio)char in deionized water. After shaking the mixture of (bio)char for one hour and after allowing deionized water to stand for one hour, the pH was measured using Mettler Toledo Seven Multi pH meter (Pundyte *et al.* 2011).

In order to determine the ash content of the (bio)char, 2 g of dried sample was placed in a pre-weighted crucible. The sample and the crucible were weighted together and then heated in a muffle furnace at 600 °C. After cooling in a desiccator, the crucible and ash were weighted. Heating was repeated for 30 min periods until constant weight. The percentage of ash was determined as follows (ASTM D2216-98):

$$\text{Total ash} = \frac{W_2 - W_c}{W_1 - W_c}\cdot 100,\ \%, \qquad (2)$$

where: W_c – the weight of the crucible, g; W_1 – the weight of the sample and crucible, g; W_2 – the weight of the ash and the crucible, g.

According to Agrafioti (2013) the dry matter content of the (bio)char was determined by oven-drying it at 105 °C until constant weight accordance to prEN 14346.

Total carbon content of (bio)char was analyzed by dry combustion with total organic carbon analyzer (TOC-V by SHIMADZU) at 900 °C (Vaitkutė *et al.* 2010).

Determination of bulk density (bio)char was based on dry matter weight and the occupied volume ratio using a standard measuring container (Komkienė, Baltrėnaitė 2014).

The concentration of heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) in the (bio)char and sludge was determined using the flame atomic absorption spectrophotometer (FAAS) (Agrafioti *et al.* 2012). Total concentration of heavy metals was determined after digestion process. Dried biochar and sludge samples were fired at 450 °C for 2.5 h to ash. Then samples (0.5 g of each sample) were mixed with 3 ml of HNO_3 (65%) and 9 ml HCl (37%), poured into special vessels and then placed into a Milestone ETHOS digester and heated for 43 min. The solution was then poured into a 50 ml flask and diluted with deionized water to reach the level of 50 ml. Filtration through a 0.45 µm membrane filter was used to remove the digestion residuals.

The blank sample was prepared in a similar way. The concentration of heavy metals in sample solutions were analyzed using FAAS or GFAAS (Pundyte *et al.* 2011).

Leaching tests

To analyze of the behavior of heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) in (bio)char two types of leaching tests – up-flow percolation test and two-stage batch leaching test – were applied.

Up-flow percolation test (CEN/TS 14405)

The up-flow percolation test was carried out using a column of 5 cm diameter. Test samples were from industrial sewage sludge produced (bio)char (particle size less than 4 mm) during pyrolysis process. The scheme of the column leaching test equipment is shown in Figure 1.

The bottom section was fitted, equipped with a filter plate and a pre-filter to the column. Then the column was filled with the (bio)char to height of 305 cm. The column was weight thus filled to an accuracy of 1 g. The dry mass (m_0) of the test portion in the column was determined.

When the column was filled with (bio)char, it was saturated with water by hydrostatic pressure. The saturated (bio)char was left for a period of 3 days in order to equilibrate the system. After the equilibration period, the hydrostatic pressure was started again and set out the flow rate such that the linear velocity is 152 cm/day through the empty column. After this, a first small portion of eluate was collected to measure the pH. The eluate portion was kept. Then the outlet hose was connected to an eluate collection bottle. The hydrostatic pressure was started again and changed the collection bottle after a quantity of (0.10.02) the mass of the test portion (m_0) of leachant has passed through. The pH of this second eluate portion (including the small portion of eluate that was used for pH measurement) was measured.

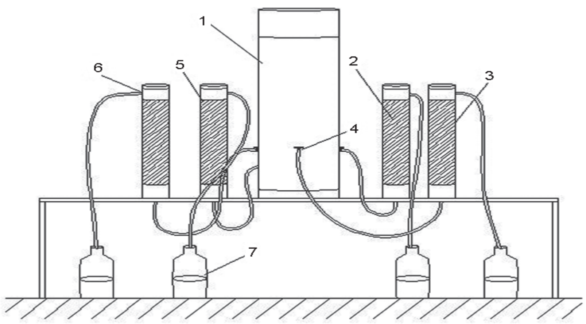

Fig. 1. The scheme of the column leaching test equipment constructed in the lab: 1 – distilled water; 2 – (bio)char as test material; 3 – column; 4 – water inlet; 5 – layer of inert material; 6 – eluate outflow; 7 – eluate collection bottles

At each eluate collection moment was measured time, volume, pH and the liquid-to-solid (L/S) ratio was calculated of the each eluate fraction.

After collection, chemical analysis of each collected eluate of heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) leached from (bio)char using leaching test was measured with FAAS or GFAAS.

Two-stage batch leaching test (EN 12457)

Batch leaching test (EN 12457) consists from 3 parts. According to Environment Agency report (2005), with the exception of L/S ratio and number of leaching steps, the general test conditions for all three parts are the same. Research was done based on the 3rd part of standard. Four samples were analyzed. Deionized water was used as the leachant and the test took a total of 24 hours. The test requires continuous agitation of the sample with deionized water using an end-over-end shaker. First leaching stage took to agitate for 6 hours, second stage – 18 hours. At first stage test portion were containing 0.181 kg, 0.177 kg, 0.177 kg, 0.175 kg (depending from dry matter content ratio) of dry mass of (bio)char. Test portions of (bio)char were placed into each bottle of 0.5 litre with 340 ml, 348 ml, 348 ml and 250 ml leachant respectively. As 95% of the sample was <4 mm.

At the second leaching stage the filtered parts of test portion along with the used filters in the first stage were placed into the second bottle of 2 litre with 1.4 l of leachant. After each agitation the suspended solids were settled for 15 minutes. The volume, temperature and pH of each filtered eluate were measured. The eluate was filtered using a vacuum filter system. Heavy metals were measured with atomic absorption spectrophotometer after first and second stage of batch test. The results of the determinations were recalculated as mg leached per kg dry residue at L/S = 2 and L/S = 10 (Environment Agency 2005).

Results and discussion

Dependence of thermal preparation of biochar samples

Biochar yield varies significantly depending on the production procedure, processing and feedstock properties (Lehmann *et al.* 2006). It was found that (bio)char yield decreased with increasing pyrolysis temperature. Results on (bio) yield are given in Table 1 (PM_B – biochar produced from paper mill industry sewage sludge, Le_B – biochar produced from leather industry sewage sludge; 450 and 600 – pyrolysis temperature; PM_SS – sewage sludge from paper mill industry, Le_SS – sewage sludge from leather industry).

Table 1. Data of (bio)char yield

(Bio)char type	%
PM_B450	54.37
PM_B600	49.35
Le_B450	49.29
Le_B600	44.67

The pyrolysis temperature is important factor affecting biochar yield. It was found that by increasing the pyrolysis temperature (in range from 450 °C to 600 °C) the yield of (bio)char decreased. The highest yield was obtained at a temperature of 450 °C with both cases – using paper mill and leather industries sludge. According to Hossain *et al.* (2011) decrease in the biochar yield is due to the decomposition of the initial feedstock and secondary reactions during the sludge pyrolysis. (Bio)char yield, when the feedstock was the paper mill industry sewage sludge at both temperatures was higher comparing with the yield of (bio)char produced from the leather industry sewage sludge.

Comparison of biochar physico-chemical properties and heavy metals concentrations with European Biochar Certificate

The pH value in biochar samples is ranging between 8.7 and 9.7 (it is classified as moderate alkalinity). The research results showed that in both type of biochar samples (paper mill industry sludge and leather industry sludge) at 450 °C pH value (respectively 8.75 and 8.71) was lower than obtained at 600 °C (respectively 9.72 and 9.57). Biochar obtained from paper mill industry sludge increase 11.08% and obtained from leather industry sludge – 9.87%. It can be concluded that pH values of both biochar samples not exceed limit value, which is described in European biochar certificate.

The carbon content of pyrolysed (bio)char fluctuates between ±5% and 95% of the dry mass, dependent on the feedstock and process temperature used. For instance the carbon content of pyrolysed poultry manure is around 25%, while that of beech wood is around 85% and that of bone is less than 10%. When using mineral-rich feedstocks such as sewage sludge or animal manure, the pyrolysed products tend to have high ash content. Pyrolysed chars with carbon contents below 50% are therefore not classified as biochar but as “Bio-Carbon-Minerals” (Schmidt *et al.* 2014).

Total carbon content C in both biochar samples varies between 15 to 23% (Table 2). According to the European Biochar Certificate, biochar’s carbon content must be higher than 50% of the dry mass. Pyrolysed organic matter with a carbon content lower than 50% are classified as Bio-Carbon-Minerals (BCM).

Concentration of metals in the biochar was found to increase with increasing temperature.

Also pyrolysis temperature had an effect on enrichment of heavy metals (Zn, Pb, Ni and Cd) in the produced biochar, which is important consideration as the heavy metals can bioaccumulate when biochars are applied to the soil (Hossain *et al.* 2011). Results of heavy metals concentration in sewage sludge and (bio)char samples are shown in Table 3.

Determination of heavy metals leaching from biochar according to LST CEN/TS 14405

The main purpose of up-flow percolation test is to determine the rate of leaching of various contaminants from granular wastes as a function of liquid to solid ratio (i.e. relative time). Data can be used as source term data for

Table 2. (Bio)char properties

(Bio)char sample	PM_B		Le_B	
Temp. of thermal treatment,	450±5	600±5	450±5	600±5
pH value	8.75±0.02	9.72±0.01	8.71±0.02	9.57±0.01
Ash content, %	3.03±0.001	7.32±0.001	15.45±0.001	13.34±0.001
Dry matter content, %	99.13±0.001	99.87±0.001	98.53±0.001	99.00±0.001
Total carbon content, %	17.47±0.01	15.54±0.01	23.44±0.01	20.17±0.01
Bulk density, g/cm3	0.40±0.02	0.41±0.01	0.47±0.02	0.53±0.01

Table 3. Heavy metals concentrations in sewage sludge and (bio)char samples, mg/kg DM

Sample	Pb	Cd	Cu	Ni	Zn	Cr
PM_SS	13.25	0.22	36.12	18.78	56.81	64.48
Le_SS	15.93	0.45	51.53	**42.48**	96.73	**803.23**
PM_B450	17.55	0.27	52.86	24.51	78.56	**99.20**
PM_B600	18.31	0.30	54.90	24.69	82.60	**115.92**
Le_B450	20.80	0.59	82.02	**53.46**	137.53	**1178.11**
Le_B600	21.09	0.60	86.09	**62.63**	148.97	**1358.47**
Basic limit value based on EBC	150	1.5	100	50	400	90
Premium limit value based on EBC	120	1	100	30	400	80

risk assessments for reuse scenarios or disposal (CEN/TS 14405; Environment Agency 2005).

The results of the determinations are recalculated as mg leached per kg dry residue and presented as cumulative L/S ratio (Table 4).

For all samples examined the concentration of heavy metals found in their leachates is low (comparing with heavy metals concentration containing in biochar). It implying that biochars significantly restrain heavy metals leaching (Agrafioti *et al.* 2012).

Comparing all analyzed heavy metals (Zn, Cr, Cd, Ni, Cu, Pb) after up-flow percolation test chromium (Cr) was leached out at least from all types biochar: in case of paper mill sludge biochar – from 0 to 0.26%; leather sludge

Table 4. Received heavy metals content in (bio)char after Up-flow leaching test, mg/kg

Sample	Content in (bio) char: 0.1	Content in (bio)char after each L/S ratio:						
		0.2	0.5	1.0	2.0	5.0	10.0	
	Pb							
PM_B450	17,55	17.51	17.47	17.35	17.19	17.02	16.69	16.36
PM_B600	18.31	18.27	18.00	17.70	17.45	17.16	16.67	16.24
Le_B450	20.8	20.76	20.79	20.77	20.75	20.73	20.71	20.70
Le_B600	21.09	21.05	21.08	21.08	21.07	21.06	20.98	20.92
Cd								
PM_B450	0.27	0.27	0.27	0.27	0.25	0.23	0.20	0.17
PM_B600	0.30	0.30	0.30	0.30	0.28	0.25	0.23	0.22
Le_B450	0.59	0.59	0.59	0.58	0.57	0.55	0.52	0.48
Le_B600	0.60	0.60	0.59	0.57	0.54	0.50	0.44	0.37
Zn								
PM_B450	78.56	78.55	78.54	78.53	78.52	78.48	78.34	78.22
PM_B600	82.60	82.60	82.59	82.57	82.56	82.54	82.52	82.50
Le_B450	137.53	137.52	137.51	137.48	137.45	137.38	137.28	137.18
Le_B600	148.97	148.96	148.91	148.85	148.80	148.75	148.64	148.54
Ni								
PM_B450	24.51	24.50	24.50	24.48	24.48	24.47	24.45	24.44
PM_B600	24.69	24.69	24.68	24.68	24.65	24.61	24.51	24.42
Le_B450	53.46	53.43	53.41	53.34	53.25	53.16	53.01	52.90
Le_B600	62.63	62.61	62.53	62.42	62.31	62.16	62.01	61.93
Cr								
PM_B450	99.20	99.18	99.17	99.15	99.12	99.10	99.01	98.95
PM_B600	115.92	115.92	115.92	115.92	115.92	115.92	115.92	115.92
Le_B450	1178.11	1177.89	1177.83	1177.73	1177.30	1176.60	1175.98	1175.42
Le_B600	1358.47	1358.42	1357.91	1356.74	1355.60	1354.47	1352.75	1352.05
Cu								
PM_B450	52.86	52.85	52.83	2.78	52.74	52.70	52.65	52.61
PM_B600	54.90	54.89	54.89	54.89	54.89	54.89	54.87	54.85
Le_B450	82.02	82.00	81.98	81.95	81.93	81.87	81.80	81.74
Le_B600	86.09	86.04	85.46	84.79	84.30	83.78	82.82	82.40

biochar – from 0.23 to 0.47% was leached out. Percentage zinc leached concentration is very similar as chromium – from 0.12 to 0.44%. Cadmium was leached out mostly from all analyzed heavy metals. Leached amount of specific heavy metal in percent after up-flow percolation test, when cumulative L/S = 10 is given in Fig. 3.7 – 3.8. L/S = 10 ratio typify longer-term leaching and are more comparable to compliance tests (Lewin *et al.* 2004).

Comparing results of up-flow percolation test can be concluded, that biochar obtained from leather industry sludge worse retain heavy metals than biochar obtained from paper mill industry sludge, because their cumulative leaching of L/S = 10 is higher. It can depend from industrial sewage sludge composition. Pulp and paper sludge is therefore a mixture of cellulose fibres, ink and mineral components. Sludge from leather industry mainly consist from water, organic substances and chromium compounds (European Communities 2001; Famielec, Wieczorek-Ciurowa 2011).

Almost in all cases the both types of biochar produced at 450 restrain heavy metals better than biochar produced at 600. Regarding Devi and Saroha (2014) the leaching potential of the heavy metals in the biochar was found to be lower compared with that in the feedstock and Zn and Cr leached concentration are the lowest – the same situation is with results of up-flow percolation test in work.

Determination of heavy metals leaching from biochar according to LST EN 12457-3

According to standard the release of a constituent at L/S = 2 and cumulative release at a cumulative L/S of 10 are recalculated as mg leached per kg dry residue (see Table 5 below).

Comparing biochar samples of industrial paper mill sludge and leather sludge it can be said that all heavy metals (Pb, Cd, Ni, Zn, Cr, Cu) leached concentrations are higher in industrial leather sludge biochar (obtained at both temperatures). The highest leaching percentage value of all heavy metal regarding paper mill sludge biochar was reached at 450 °C, in case of leather sludge biochar – at 600 °C. See Table 6, which shows the highest leaching values in percent from all (bio)char samples obtained from industrial leather and paper mill sludge (at L/S = 2 or L/S = 10).

Batch tests often lead to enhanced mobilization of colloids due to the agitation. Those particles often contain colloidal-linked pollutants, therefore the eluate has to be centrifuged and/or filtrated in order to avoid an overestimation of contaminant release (Krüger *et al.* 2012).

The all heavy metals concentrations in leather and paper mill industry sludge (bio)char were lower in the eluate after first stage of batch test than in filtrate after second stage of batch test. At L/S = 10 both the batch leaching test

Table 5. Leached metals content, mg/kg

Sample	Leached content after two stage batch test at:		Sample	Leached content after two stage batch test at:	
	L/S 2	L/S 10		L/S 2	L/S 10
Pb			Pb		
PM_B450	0.150	0.409	Le_B450	0.753	1.463
PM_B600	0.014	0.058	Le_B600	2.239	2.475
Cd			**Cd**		
PM_B450	0.005	0.004	Le_B450	0.004	0.019
PM_B600	0.001	0.0002	Le_B600	0.006	0.020
Ni			**Ni**		
PM_B450	0.130	0.510	Le_B450	0.630	0.980
PM_B600	0.140	0.400	Le_B600	1.370	2.870
Zn			**Zn**		
PM_B450	0.091	0.390	Le_B450	0.134	0.799
PM_B600	0.027	0.076	Le_B600	0.192	0.421
Cr			Cr		
PM_B450	1.160	1.236	Le_B450	0.830	7.319
PM_B600	1.118	1.254	Le_B600	2.280	8.751
Cu			**Cu**		
PM_B450	0.069	0.153	Le_B450	0.396	0.428
PM_B600	0.013	0.076	Le_B600	0.433	0.636

Table 6. Leached concentrations of specific heavy metal in percent after batch test

Heavy metal	Leaching of specific heavy metal in percent after Batch test	
	The highest leaching value in paper mill sludge (bio)char, %	The highest leaching value in leather sludge (bio)char, %
Pb	0.075	0.248
Cd	0.0005	0.0020
Ni	0.05	0.287
Zn	0.039	0.080
Cr	0.125	0.875
Cu	0.015	0.064

and the up-flow percolation test resulted in high amounts of elements leached comparing with L/S = 2. There is generally a great difference between the leaching results at L/S 2 and L/S 10, with leaching at L/S 10 generally greater than at L/S 2 (Mellbo *et al.* 2008).

Comparing up-flow and batch test results, the calculated release rates of the column tests eluates up to L/S 10 L/kg were cumulated and are higher than batch test release. The difference between column and batch test results might be due to varying sample properties and test conditions (Grathwohl, Susset 2009).

Conclusions

1. The yield of (bio)char obtained from sewage sludge of paper mill and leather industries was lower at 600 °C.
2. The value of both types of (bio)char samples (paper mill industry sludge and leather industry sludge) at 450 °C pH was lower than obtained at 600 °C. pH values of both (bio)char samples did not exceed the limit value (pH > 10).
   Ash content and bulk density were higher in (bio)char obtained from leather industry sewage sludge.
3. Nickel concentration in (bio)char obtained from leather industry sludge almost 2 times exceed threshold for premium (bio)char (Ni < 30 g/t). All (bio)char samples exceed threshold values of chrome for premium (bio)char (Cr < 80 g/t). Cd, Pb, Zn, and Cu concentrations did not exceed limit values.
4. Leaching test showed that (bio)char obtained from leather industry sludge worse retain heavy metals than (bio)char obtained from paper mill industry sludge.

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IŠ GAMYBINIO NUOTEKŲ DUMBLO PAGAMINTOS BIOANGLIES SUNKIŲJŲ METALŲ IŠPLOVIMO ĮVERTINIMAS

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Santrauka

Bioanglis gali būti gaminama iš daugelio įvairių pramonės žaliavų, įskaitant biomasės liekanas, pavyzdžiui, šiaudus, šakas, pjuvenas ir kitas žemės ūkio ir miškininkystės atliekas. Viena iš alternatyvų – bioanglį gaminti iš pramonės nuotekų dumblo, tačiau tokį produktą galima naudoti ribotai dėl jame esančio didelio sunkiųjų metalų kiekio. Iš bendrosios sunkiųjų metalų koncentracijos tyrimų galima tik ribotai spręsti apie sunkiųjų metalų pasiskirstymą, todėl buvo taikomi du tyrimai: tyrimas, perkoliuojant atliekas vienakrypte srove, bei dvipakopis partijos (tyrinio) tyrimas siekiant išanalizuoti sunkiųjų metalų (Cd, Pb, Cr, Ni, Zn, Cu) išplovimą iš bioanglies, pagamintos iš dviejų rūšių nuotekų dumblo: popieriaus gamybos ir odos pramonės.

Reikšminiai žodžiai: bioanglis, praplovimo tyrimai, pirolizė, sunkieji metalai.