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Characteristics of Bottom Ash from Municipal Solid Waste Incineration

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1. Introduction

Increasing population, rapid urbanization and developing living standards generates large amounts of municipal waste (Jin et al. 2012, Arena & Di Gregorio 2014, Lin et al. 2015, Adamcová et al. 2016). Therefore, collection, recycling, treatment and disposal of increasing quantities of solid waste are a big challenge for municipalities, and therefore waste management is one of the main priorities of environmental protection (Turskis et al. 2012, Pinto et al. 2014, Tan et al. 2014). The Integrated Solid Waste Management (ISWM) includes several solutions to reduce negative impact on the environment and mankind. This alternative combines the reduction of waste generation, the materials recovery, the recycling, the energy recovery and waste landfilling (Leme et al. 2014).

In many countries, after recovery of recyclable materials, a large part of municipal solid waste (MSW) is disposed in landfills (Ferraris et al. 2009, Ghinea & Gavrilescu 2016). In recent years biofuel production from agricultural waste and biomass as well as waste-to-energy (WTE) technologies from MSW have been actively investigated (Ng at al. 2014). WTE is widely used in many countries around the world, and one such technology is MSW incineration (Rocca et al. 2012, Zhou et al. 2015).

Using municipal solid waste incineration (MSWI) can help recover energy (heat and electricity) and reduce the waste volume by 90% (the waste mass by 70%) (Veli et al. 2008, Santos et al. 2013, Zhou et al.

2014, Rentizelas et al. 2014). During the incineration process, different gaseous emission and solid residues are generated. Two main types of by-products are fly ash (FA) and bottom ash (BA), the latter accounting for 80-85% of all the residues (Cornelis et al. 2012, Allegrini et al. 2014, Lin et al. 2015, Tang et al. 2015, Di Gianfilippo et al. 2016, Holm & Simon 2017). BA contains inorganic matter (stone, ceramic, glass), ferrous and non-ferrous metals and small quantities of unburned organic matter (plastic, fibre, wood etc.) (Tang et al. 2015, Allegrini et al. 2016, Chang et al. 2015). Unlike FA, BA is classified as non-hazardous waste by the European Waste Catalogue. MSWI bottom ash is composed mainly of silica, alumina, calcium and iron oxide, which are natural aggregate compounds (Del Valle-Zermeño et al. 2015, Su et al. 2013, Del Valle-Zermeño et al. 2016, Xia et al. 2017,). BA properties differ from plant to plant and from country to country (Zekkos et al. 2013). Table 1 presents the chemical compositions of BA that was generated in MSWI plants in various European countries.

Also, without these oxides in BA were found soluble salts, such as chlorides, sulphates, fluorides, bromides, and many heavy metals, such as copper, zinc, lead, chrome, nickel and cadmium. Research on BA composition carried out in various countries showed the presence of high amounts of chlorides (up to 5,900 mg kg^{-1}), sulphates (up to 7,000 mg kg^{-1}) (Santos et al., 2013, Lin et al., 2015, Tang et al., 2015) and heavy metals, such as zinc (903-7,732 mg kg^{-1}), lead (1,022-4,552 mg kg^{-1}), copper (1,041-7,743 mg kg^{-1}) and barium (1,300-3,920 mg kg^{-1}). In addition, chromium, nickel and arsenic were found (Rambaldi et al. 2010, Bayuseno & Schmahl 2010, Su et al. 2013, Tang et al. 2016).

Landfilling and and using in civil engineering are the most commonly used BA management technologies in the world (Ore et al. 2007, Haiying et al. 2011, Torlando et al. 2013, Gori et al. 2013, Del Valle-Zermeño et al. 2014b). Owing to atmospheric precipitation and various chemical reactions in landfills, leachate is formed. It contains various heavy metals and salts. A leachate can cause harmful effects in soil and underground water if it gets into the environment (Yao et al. 2014, Mucsi et al. 2016).

Table 1. Chemical composition of major oxides in MSWI bottom ash in various European countries
Tabela 1. Skład chemiczny podstawowych tlenków w popiele dennym ze spalania stałych odpadów komunalnych (SOK) w różnych krajach europejskich

Oxide	Amount, % wt						
	Netherlands (Tang et al. 2015)	Spain (Del Valle-Zermeño et al. 2014a)	Italy (Rambaldi et al. 2010)	Germany (Müller & Rübner, 2006)	Slovenia (Jurič et al. 2006)	Sweden (Lidelöw & Lagerkvist 2007)	France (Rednek et al. 2007)
SiO_2	54.23	43.3	33.70	55.70	24.00	37.00	47.82
CaO	13.45	16.9	35.00	11.9	39.00	15.00	15.99
Fe_2O_3	13.83	14.1	5.37	8.80	2.70	15.00	6.23
Na_2O	2.81	7.58	2.27	1.40	0.90	0.28	6.34
Al_2O_3	7.86	5.80	13.31	14.1	14.8	13.00	8.63
MgO	1.81	2.22	4.62	2.70	1.70	0.25	2.38
K_2O	0.88	1.11	1.66	1.2	0.20	0.14	n. d.

Note: n. d. – no data

The aim of this study is to determine the chemical composition of the BA, and eluate parameters such as quantities of heavy metals, chlorides and sulphates, and pH. In this study, the bottom ashes were provided by the waste-to-energy plant, which is located in Klaipėda, in Lithuania. The incineration plant in Klaipeda became operational in 2013. Combustion chamber capacity is 255,000 tonnes of solid fuel per year. The feed stream is commonly composed of household waste, commercial waste in lower proportions and solid biofuel (wood processing waste). In the various regions of Lithuania household waste that is collected first goes through a separation line to extract the recyclable materials (metals, plastics, paper and glass), before being incinerated.

2. Materials and methods

The representative six BA samples (30 kg each) were collected from the different spots of the large BA piles once a week (in February-April 2016) and sealed in plastic buckets before testing.

The moisture content was determined using the oven-drying method: a test portion (2 kg) after homogenization and weighting was dried in the oven at 105°C until a constant mass. Moisture content in BA was determined according to the formula (Willits 1951):

$$w_w = (m_a/m_b) \cdot 100 \tag{1}$$

where:
w_w – the moisture content (%),
m_a – the mass of the dried sample (g),
m_b – the mass of sample (g)

The chemical composition of the major and minor elements in MSWI bottom ash was determined in duplicate by X-ray Fluorescence Spectroscopy (XRF) using an Axios mAX X-ray spectrophotometer.

The compliance leaching test was performed according to the Standard LST EN 12457-2:2003. The samples, which originally and after pretreatment were below 4 mm in size, were put in contact with distilled water in capped bottles. The solid to liquid ratio was 1/10 (90 g dry BA and 900 mL distilled water), and the suspension was agitated for 24 h at room temperature (20±5°C). Solid residue was separated by filtration.

Eluate pH (Metler Toledo) and conductivity (WTW Terminal 740) were determined. Furthermore, after acidification (pH 2 using HNO_3), 18 metals content was analysed by AAS according to ISO 15586:2003.

Soluble salts (chlorides, sulphates, bromides and fluorides) concentration in eluate was determined by liquid chromatography of ions, according to LST EN ISO 10304-1:2009. Further, total organic carbon (TOC) and dissolved organic carbon (DOC) were determined according to LST EN 13137:2002 and ISO 8245:2003 standards.

The amount of total dissolved solids (TDS) was determined by the evaporation procedure: 50 mL of eluate is placed in the weighed porcelain dish, to which is added 0.5 mL of concentrated hydrochloric acid. The sample is placed on a hotplate until completely evaporated. After evaporation the porcelain plates are once again weighed. The amount of TDS calculated according to (2) the formula:

$$TDS = [(m_e\text{-}m_d) \cdot 1000]/v \quad (2)$$

where:
TDS – concentration of total dissolved solids (mg/L),
m_d – mass of empty porcelain dish (mg),
m_e – mass of porcelain dish after evaporation (mg),
v – volume of eluate (mL).

The results of eluate parameters were compared with the limit leaching values for inert and non-hazardous waste, according to the 2003/33/EC.

3. Results and discussion

3.1. Water content in BA

After drying six samples to constant weight the amount of water was prescribed by Eq. (1). The results are shown in Figure 1.

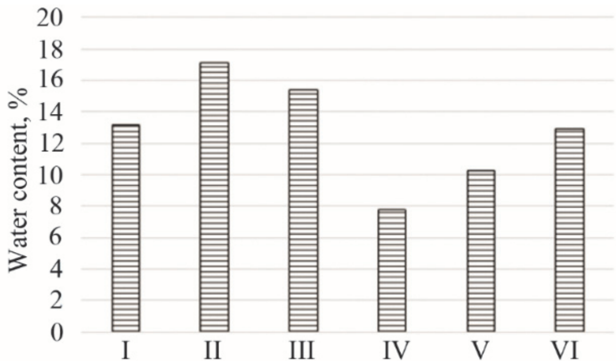

Fig. 1. Moisture content in MSWI bottom Ash
Rys. 1. Zawartość wilgoci w popielie dennym ze spalania SOK

The results (Fig. 1) reveal that fresh (not aged) BA water content varies from 7.80 to 17.16%. Water content values are not stable because BA in the waste incineration plant is cooled by water. One part of the cooling water evaporates immediately, while the other part is absorbed by BA.

3.2. Chemical composition of BA

The six samples' BA chemical composition determination research showed that the main components (>10%) were silicon and calcium. Also found were (1-8%) aluminum, magnesium, sodium, potassium and iron. The aforementioned elements were found in the form of oxides. Review of scientific literature shows that silicon, a part of silicon dioxide (SiO_2), is the main element of the composition of BA (Jurič et al. 2006, Müller et al. 2006, Lidelöw & Lagerkvist 2007, Rednek et al. 2007, Rambaldi et al. 2010, Cheng 2012, Li et al. 2012, Abbà et al. 2014, Del Valle-Zermeño et al. 2014a, Del Valle-Zermeño et al. 2015, Tang et al. 2015). The researches show (Figure 2) that this oxide constitutes more than half (57±2%) of the total weight of BA. In its composition also is 16±2.5% CaO, 8±3.2% Fe_2O_3, 5±1% Na_2O and 5±0.5% Al_2O_3.

Comparing of the study results with bottom ash composition in other countries (Table 1), we see that the BA composition are most similar to BA which formed in Spanish and French incineration plants.

Silicon oxide content in BA from Italian (Rambaldi et al. 2010), Slovenian (Jurič et al. 2006) and Swedish (Lidelöw & Lagerkvist 2007) incineration plants is 1.54-1.69 times lower than in BA from Lithuania (56.94%). Amount of SiO_2 are almost the same in BA of Lithuania plant and in BA witch are generated in German plant (Müller & Rübner 2006). After sorting, the remaining waste contains a significant proportion of inert waste (such as glass, construction and demolition waste, ceramics, etc.), and therefore BA contains a high amount of SiO_2.

Amount of calcium oxide in different countries MSWI BA is 11.9-39.0% (Table 1), in Lithuanian BA – 16.12%. Similar CaO content as determined in the Spanish, Swedish and French bottom ashes. Amount of CaO in the BA is mostly dependent on a variety of paper waste in incinerated waste stream.

Content of iron oxide in different countries BA varies highly (2.70-14.10%), this study showed that the BA from Lithuania plant average contains of 7.82% Fe_2O_3. The separation of ferrous metals from BA, using magnetic separation method, leads the relatively small amount of Fe_2O_3.

Comparing other countries (Table 1) and the results of Lithuania, the content of aluminum in Lithuanian BA is lowest (approximately 4.88%). Literature analysis showed that the highest amount of Al_2O_3 (14.1-14.8%) are found in BA from Germany and Slovenia plants (Jurič et al., 2006, Müller and Rübner, 2006). It can be assumed that in incinerated waste stream enters a small amount of aluminum waste (foil, drinks cans, etc.) in Lithuania. Operating a deposit system for drinks cans can lead a small amount of aluminum waste in the stream.

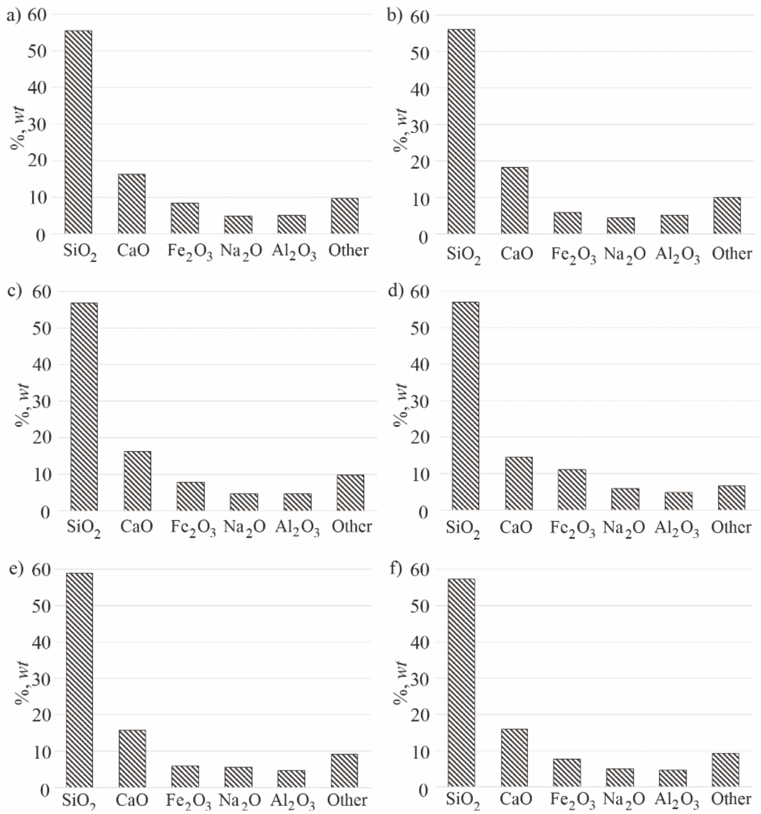

Fig. 2. Concentrations of major oxides MSWI bottom ash, sample number: a) I; b) II; c) III; d) IV; e) V; f) VI

Rys. 2. Zawartość podstawowych tlenków w popiele dennym ze spalania SOK, numer próbki: a) I; b) II; c) III; d) IV; e) V; f) VI

Concentrations of heavy metals (Ba, Mn, Cu, Pb, Sr, Cr, Sn, Ni) in BA were relatively low (<1%). The highest amounts were of barium (2,780-4,190 mg kg^{-1}), manganese (700-1,160 mg kg^{-1}), lead (670-1,760 mg kg^{-1}) and zinc (1,330-2,010 mg kg^{-1}). The amounts of minor elements in the six samples of MSWI bottom ash are shown in Figure 3.

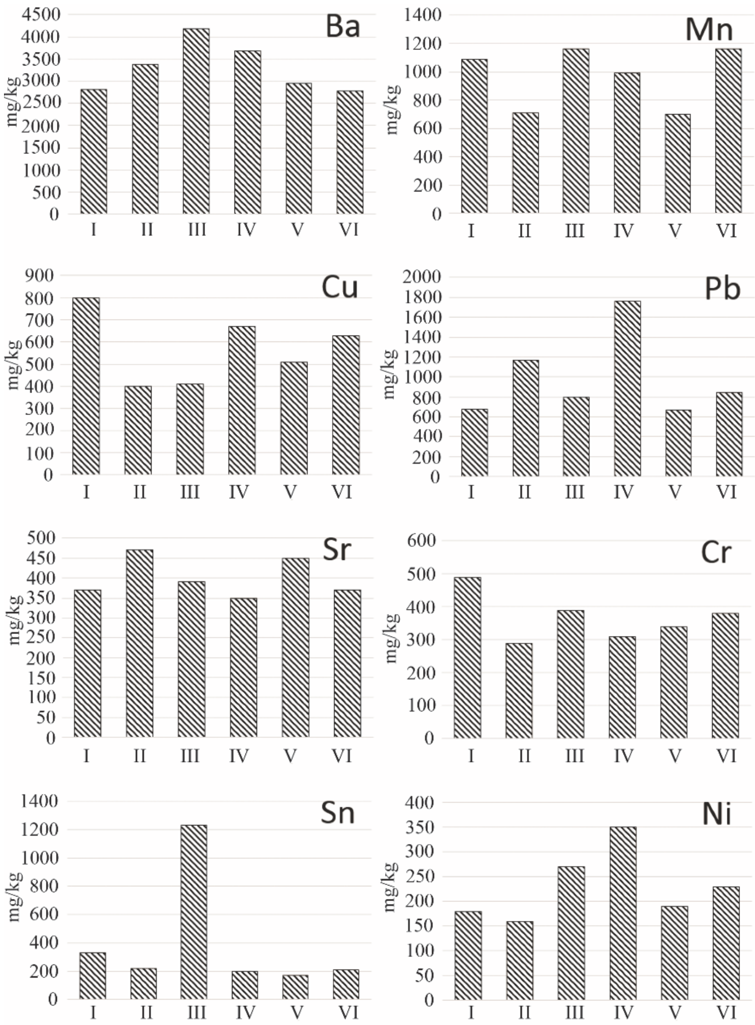

Fig. 3. Concentrations of minor elements (heavy metals) in MSWI bottom ash
Rys. 3. Zawartość drugorzędnych pierwiastków (metali ciężkich) w popiele dennym ze spalania SOK

The chemical composition of BA depends mainly on the initial composition of the incinerated waste and BA pretreatment technology. It can be concluded that the main elements (SiO_2, CaO_2) are almost constant in time but that concentrations of heavy metals vary.

3.3. Leaching Results

The results of the natural pH batch leaching tests on the collected materials are shown in Table 2 and Table 3. The leaching data are compared with the European Commission decision 2003/33/EC regulatory limit values for waste removal in inert and non-hazardous waste landfills.

Table 2. Heavy metals concentrations in MSWI BA eluate (mg kg^{-1})
Tabela 2. Stężenie metali ciężkich (mg kg^{-1}) w popiele dennym ze spalania SOK

Element, parameter	I sample	II sample	III sample	IV sample	V sample	VI sample	2003/33/EC	
							Inert waste	Non-hazardous waste
Arsenic (As)	0.01	0.01	0.01	0.01	0.01	<0.01	0.5	2
Barium (Ba)	3	5	5	3	4	5	20	100
Cadmium (Cd)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.04	1
Chrome (Cr)	0.2	0.3	0.2	0.1	0.3	0.2	0.5	10
Copper (Cu)	2	1	2	1	0.1	0.1	2	50
Mercury (Hg)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	0.2
Molydenum (Mo)	0.9	1.0	1.8	1.8	0.5	0.8	0.5	10
Nickel (Ni)	<0.02	<0.02	<0.02	<0.02	0.03	0.08	0.4	10
Lead (Pb)	2.3	2.4	2.5	0.3	0.1	0.2	0.5	10
Antimony (Sb)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	0.7
Selenium (Se)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.1	0.5
Zinc (Zn)	5	2	2	0.4	1	1	4	50

Table 3. MSWI bottom ash eluate characteristics
Tabela 3. Charakterystyka eluatu z popiołu dennego ze spalania SOK

Element, parameter	I sample	II sample	III sample	IV sample	V sample	VI sample	2003/33/EC	
							Inert waste	Non-hazardous waste
Chlorides (Cl), mg kg^{-1}	2,259	2,441	3,046	2,006	1,869	2,330	800	15,000
Fluorides (F), mg kg^{-1}	2	3	2	3	2	2	10	150
Bromides (B), mg kg^{-1}	8	7	13	5	8	1	N*	N*
Sulphates (SO_4), mg kg^{-1}	6,687	7,120	10,012	4,273	3,566	2,816	1,000	20,000
Total dissolved solids (TDS), mg kg^{-1}	32,917	32,000	40,443	22,998	21,663	28,575	4,000	60,000
Dissolved organic carbon (DOC), mg kg^{-1}	139	123	171	82	71	55	500	800
Total organic carbon (TOC), mg kg^{-1}	2,380	1,550	2,150	2,760	2,710	1,880	30,000	5%
pH	12.7	12.6	12.6	12.5	12.4	12.6	N*	>6
Acid neutraliza-tion capa-city (ANC), mol kg^{-1}	1.78	2.76	2.53	1.64	2.33	2.76	N*	Must be evaluated
Electrical conducti-vity (EC), µS cm^{-1}	8,900	8,750	9,530	6,260	5,820	8,240	N*	

Note: *Not regulated

Concentrations of five metals (As, Cd, Hg, Sb, Se) were <0.01 mg kg^{-1}. Mo, Pb, Zn concentrations in eluate were 0.5-1.8 mg kg^{-1}, 0.1-2.5 mg kg^{-1} and 0.4-5.0 mg kg^{-1}, respectively. The concentration of molybdenum in five eluate samples was higher than the permissible concentration of inert waste eluates, namely 0.5 mg kg^{-1}, lead three times (0.5 mg kg^{-1}) and zinc (4 mg kg^{-1}) one time. It can be assumed that the high concentrations of metals in eluate were for incomplete separation of metals from BA.

Also determinated were the concentrations of sulphate, chloride, bromide and phosphate in eluates, as well as parameters such as electrical conductivity, pH, quantities of dissolved and total carbon, and acid neutralization capacity. The results are given in Table 3.

When the BA affects the fluid (in this case distilled water, and deposited BA in landfills – precipitation), the salts (chlorides and sulphates) that are contained in BA melt and pass into the solution. Table 3 data show that the concentrations of sulphates (4,273-10,012 mg kg^{-1}), chlorides (1,869-3,046 mg kg^{-1}) and TDS (21,663-40,443 mg kg kg^{-1}) are high. Concentration of chlorides 2.3/3.8 times, sulphates 2.8/10.0 times and TDS 5.4/10.1 times were higher than the permissible concentrations for inert waste eluates.

It was established that there is a strong correlation between total dissolved solids and electrical conductivity ($R^2 = 0.9031$) (Fig. 4).

The researchers have carried out various analysis to find out the mathematical correlation between TDS and EC values, therefore TDS concentration can be estimated from EC value. However, relations between TDS and EC is not directly linear, because ionic species conductivity of mobility is variable. (Brown et al. 1960, Walton 1989, Patil et al. 2012, Marandi et al. 2013). The correlation bettwen TDS and EC calculated according to (3) the formula:

$$TDS = k \cdot EC \qquad (3)$$

where:
TDS – concentration of total dissolved solids (mg/L),
k – value, which depends on the concentration of ions in eluate
(k will increase along with the increase of ions in liquid),
EC – electrical conductivity (μS cm^{-1}).

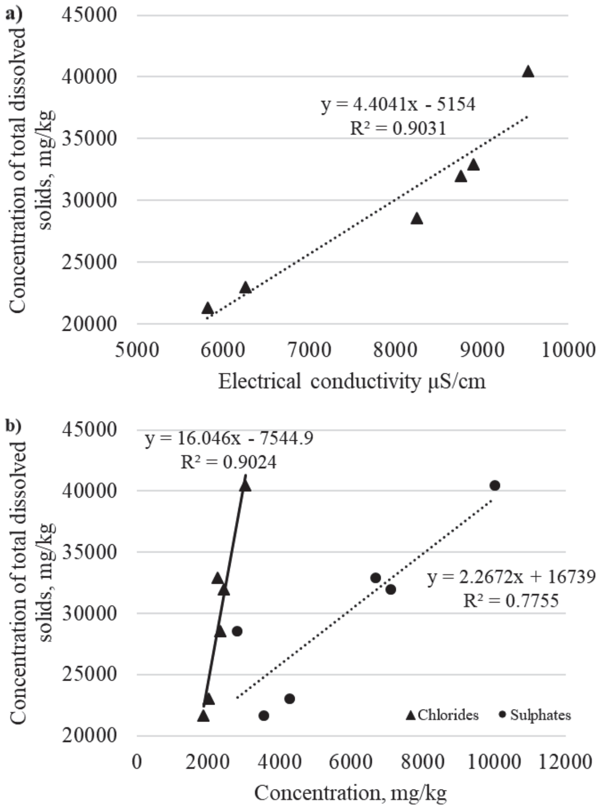

Fig. 4. Correlation relations in MSWI bottom ash eluate: a) correlation between total dissolved solids and electrical conductivity; b) correlation between total dissolved solids, chlorides and sulphates concentration
Rys. 4. Relacje korelacyjne w eluacie z popiołu dennego ze spalania SOK: a) korelacja między przewodnictwem i stężeniem substancji rozpuszczonych; b) korelacja między stężeniem substancji rozpuszczonych i stężeniem chlorków oraz siarczanów

This expression is approximate, because nonionic species does not affect EC values and ionic species have unequal weights. The actual multiplier (k) depends on indvidual mobility of dissolved ions and and the average mobility of all ions, which in turn depends on the temperature of the liquid, the relative amount of differents ions and the total concentration of soluble solids (Thirumalini & Joseph 2009). Based on formula 3 and the results of the TDS and EC values determination, was found that k values are 3.47-4.24. Then in natural water, than EC = 500-3000 µS cm^{-1}, k value ranges from 0.55 to 0.75). (Brown 1960, Thirumalini & Joseph 2009, Rusydi 2018).

Figure 4 b shows strong relations between TDS and chlorides (R^2 = 0.9024) and sulphates (R^2 = 0.7755). Bearing in mind that the TDS consists of various inorganic anions (carbonates, chlorides, sulfates and nitrates) and inorganic cations (sodium, potassium, calcium and magnesium), these correlations is quite predictable. Thirumalini1 & Joseph (2009) claims that linear coefficient of correlation (r) among the TDS and clorides in fresh water can be 0.95, and respectively between TDS and suphates 0.82.

Concentrations of fluorides and bromides were quite low (2-3 mg kg^{-1} and 1-13 mg kg^{-1} respectively). Also, total (TOC) and dissolved organic carbon (DOC) quantities in MSWI bottom ash eluate were determined to be 1,550-2,760 mg kg^{-1} and 55-171 mg kg^{-1}. Figure 5 shows the correlation of copper, lead and DOC concentrations in eluate.

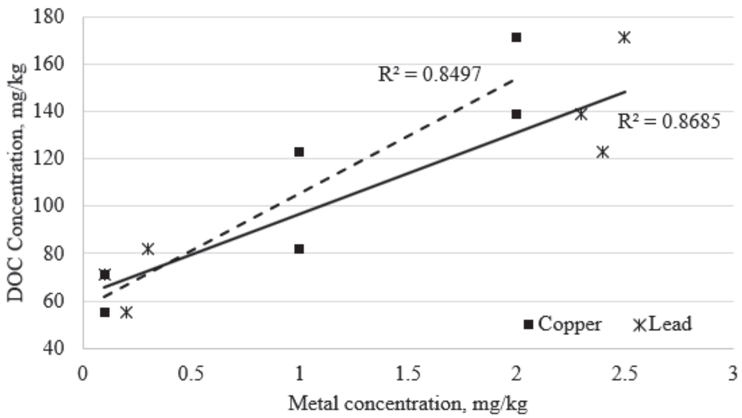

Fig. 5. Correlation of copper, lead and DOC in eluate from MSWI bottom ash
Rys. 5. Korelacja między zawartością miedzi, ołowiu oraz rozpuszczonego węgla organicznego w eluacie z popiołu dennego ze spalania SOK

The graphs in Fig. 5 show that copper and lead concentrations in the eluate have a strong dependence on DOC. It was found that copper and DOC correlation coefficient $R^2 = 0.8497$, lead and DOC – $R^2 = 0.8685$.

Van der Sloot et al. (2000) and Robinson et al. (2004) contend that organic complexation has a significant influence over Cu leaching from BA.

The eluate at all times was alkaline (pH = 12.5±0.2), electrical conductivity – 5,820-9,530 µS cm^{-1} and acid neutralization capacity – 2.2±0.56 mol kg^{-1}. According to the obtained values (Table 3), neither parameter exceeded the limit values for waste removal in non-hazardous waste landfills.

As previously mentioned, one possible BA reuse option is production of road and construction structural elements of inert material, replacing part of the inert material in BA. Currently, this technology is only beginning to be used in Lithuania. This technology is widely used in Germany, Denmark, France, Italy and the Netherlands. Table 4 presents a comparison of the eluate parameters maximum values and leaching limit values of BA in Lithuania (D1-805) and in Germany (LAGA 20).

Table 4. Comparison of the eluate parameters maximum values and BA leaching limit values in Lithuania and Germany, mg kg^{-1}
Tabela 4. Porównanie wartości maksymalnych parametrów w eluacie oraz wartości granicznych ługowania popiołu dennnego na Litwie i w Niemczech, mg kg^{-1}

Element, parameter	Sign	Units	This study	Lithuanian limit values (D1-805)	German limit values (LAGA 20)
Chlorides	Cl	mg kg^{-1}	3,046	1,000	2,500
Sulphates	SO_4	mg kg^{-1}	10,012	2,000	6,000
Lead	Pb	mg kg^{-1}	2.5	0.5	0.5
Cadmium	Cd	mg kg^{-1}	<0.003	0.03	0.05
Chrome	Cr	mg kg^{-1}	0.3	2	2
Copper	Cu	mg kg^{-1}	2	1.5	3
Mercury	Hg	mg kg^{-1}	<0.001	0.001	0.001
Nickel	Ni	mg kg^{-1}	0.08	0.4	0.4
Zinc	Zn	mg kg^{-1}	5	3	3

Table 4 data show that the maximum concentrations of the four parameters Cl, SO_4, Pb and Zn, which are, respectively, 3,046 mg kg^{-1}, 10,012 mg kg^{-1}, 2.5 mg kg^{-1} and 5 mg kg^{-1}, are higher than the limit values of BA in Lithuania and Germany. One metal (copper) maximum concentration (2 mg kg^{-1}) is higher than permissible value in Lithuania, which are 1.5 mg kg^{-1}.

It can be concluded that the unprocessed BA generated in the MSWI plant in Klaipėda cannot be used in concrete and road construction elements. The document (D1-805) which describes possibilities for BA utilization in civil and conctruction engineering in Lithuania, states that BA must be exposed to natural aging (weathering) for at least three months first. It can be assumed that, after the natural aging process of BA from the Klaipėda MSWI plant, leaching values will be smaller than limit values.

4. Conclusions

The six samples of BA chemical (elemental and oxide) composition analysis show that the chemical composition of the time is variable. The main elements of the BA are silica (57±2%), calcium (16±2.5%), iron (8±3.2%), sodium 5 (±1%) and aluminum (5±0.5%) oxides. A wide range of heavy metals are also found in the BA. The highest concentrations are barium (2,780-4,190 mg kg^{-1}), manganese (700-1,160 mg kg^{-1}), lead (670.0-1,760 mg kg^{-1}) and zinc (1,330-2,010 mg kg^{-1}).

MSWI bottom ash does not meet the requirements for inert waste (2003/33/EC) because were too high concentrations of Mo (0.5-1.8 mg kg^{-1}), Pb (2.5-12.2 mg kg^{-1}), Zn (5 mg kg^{-1}), Cl (1,869-3,046 mg kg^{-1}), SO_4 (4,273-10,012 mg kg^{-1}) and TDS (21,663-40,443 mg kg^{-1}) in the eluate. But BA parameters meet the requirements for the waste removal in non-hazardous waste landfills.

The results of the study have shown that the concentration of TDS is directly dependent on the electrical conductivity (0.9031) and quantity of chlorides ($R = 0.9024$) and sulphates ($R = 0.7755$) in BA eluate. Further, a correlation was found between the concentrations of copper, lead and dissolved organic carbon. The correlation coefficients are, respectively, 0.8497 and 0.8685. Heavy metal (Cu, Pb) concentrations correlation on the DOC can be explained by organic complexation processes.

Changing concentrations of the environmentally hazardous heavy metals (Zn) and soluble (Cl, SO_4) salts indicate that BA cannot be used in concrete and road construction elements. First necessary full separation of metals and BA aging, at least three months. After that continuous BA eluate test is important in order to assess the BA application possibilities in the civil and construction engineering fields.

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Charakterystyka popiołów dennych ze spalania stałych odpadów komunalnych

Streszczenie

Technologie produkcji energii z odpadów są szeroko stosowane w gospodarce odpadami komunalnymi. Spalanie stałych odpadów komunalnych zmniejsza ich objętość o 90%. W procesie spalania wytwarzane są dwa główne typy produktów ubocznych: popioły lotne (PL) i popioły denne (PD). W pracy omówiono właściwości chemiczne i środowiskowe PD pochodzących ze spalania stałych odpadów komunalnych (SOK). Określono skład chemiczny i wymywanie substancji z PD z litewskiej spalarni odpadów, której siedziba mieści się w Kłajpedzie. Wyniki pokazują, że skład chemiczny PD jest prawie stabilny w czasie, a podstawowe tlenki to dwutlenek krzemu (57±2%), tlenek wapnia 16±2,5% i tlenek żelaza 8±3,2%.

Koncentracja różnych metali ciężkich w PD wynosi < 1%. Badania wymywania wykazały, że z PD wymywano duże ilości rozpuszczalnych soli (siarczanów 2 816-10 012 mg kg^{-1} i chlorków 1 869-3 046 mg kg^{-1}), a także niektórych metali ciężkich (Mo 0,5-1,8 mg kg^{-1}, Pb 0,1-2,5 mg kg^{-1}). Popiół denny ze spalania stałych odpadów komunalnych nie spełnia wymagań dotyczących odpadów obojętnych (2003/33/WE), ale spełnia wymagania dotyczące ich usuwania na składowiska odpadów innych niż niebezpieczne. Zmieniające się koncentracja niebezpiecznych dla środowiska metali ciężkich wskazuje na konieczność ciągłego badania eluatu z popiełów dennnych.

Abstract

Waste-to-energy technologies are widely used for municipal solid waste management. Municipal solid waste incineration has reduced waste volume by 90%. The combustion process results in two types of waste: fly ash (FA) and bottom ash (BA). This study focuses on the chemical and environmental properties of municipal solid waste incineration (MSWI) bottom ash. The chemical composition and leaching properties of BA from Lithuania's waste-to-energy plant, located in Klaipeda, was determined. Results show that chemical BA composition is almost stable in time and that major elements are silicon dioxide (57±2%), calcium oxide 16±2.5% and iron oxide 8±3.2%.

The concentration of various heavy metals in BA is < 1%. Leaching tests showed that from BA leached large quantities of soluble salts (sulphates 2,816–10,012 mg kg^{-1} and chlorides 1,869–3,046 mg kg^{-1}) and certain heavy metals (Mo 0.5–1.8 mg kg^{-1}, Pb 0.1–2.5 mg kg^{-1}). MSWI bottom ash does not meet the requirements for inert waste (2003/33/EC) but meets those for waste removal in non-hazardous waste landfills. The changing concentration of environmentally hazardous heavy metals indicates that the need for continuous BA eluate test is important.

Słowa kluczowe:
spalanie odpadów komunalnych stałych, popiół denny, metale ciężkie, sole rozpuszczalne

Keywords:
municipal solid waste incineration; bottom ash; heavy metals; soluble salts