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PROPERTIES AND RECYCLING FEASIBILITIES OF MUNICIPAL SOLID WASTE INCINERATION RESIDUES: ISSUES FOR KAUNAS WASTE INCINERATION PLANT, LITHUANIA

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Municipal solid waste (MSW) is considered waste from households, as well as other waste, that is in nature or composition similar to waste from households. Mainly MSW consists of paper, cardboard, plastics, glass, organic matter and metals. Continuously growing worldwide population, improved living standards and urbanisation processes increase the amount of generated waste. Most simple, inexpensive and convenient way to dispose MSW is landfilling which has the highest negative environmental impact, just landfill sites contribute 20% of the global anthropogenic methane emissions [2].

Collected waste pre-processing makes it possible to recover and reuse valuable resources such as plastics, paper fibers and metals. For instance, manual separation can further extract material for recycling. Especially efficient use of MSW stream is preparation of refuse-derived fuel (RDF) that largely consists of plastic and fiber waste with high level of organic content. For preparation of this fuel, it is needed advanced pre-screening and processing, including mechanical–biological treatment (MBT) [8]. Using MBT facilities for MSW treatment is a common practice throughout Europe. In the treatment process stages, from waste can be quickly and safely driven out of moisture, producing dry output that later can be prepared for incineration. In 2020, Kaunas MBT facility has processed 142,59 thousand tons of MSW, from which 55,94 thousand tons of RDF were transported for incineration to Kaunas and Klaipeda waste incineration plants. About 1780 tons of recovered material such as (PET, HDPE, LDPE, ferrous and nonferrous metals) were recycled. 30,1 thousand tons of waste were sent to landfill [4].

Municipal solid waste incineration (MSWI) is a waste management technology that has increasingly been adopted around the world [12]. Substantial amount of total waste mass and volume is lost, when bottom ash is generated by waste incineration plants. The primary type of waste supplied to the municipal incineration plants is household waste [3]. It is very common before incinerating municipal waste to include pre-processing. On this day in Lithuania there are 3 working MSWI plants, located in Klaipėda, Kaunas and capital Vilnius. In these plants, incineration process is based on moving grate principle. After incineration of waste feed in primary combustion chamber, generated bottom ash and slag and also settled dust on boilers are considered non-hazardous waste and in accordance with EU 2008/98/EB Directive are marked by 19 01 12 and 19 01 16 codes, which are identified as treated waste after waste treatment installations, in this case incineration. Kaunas waste incineration plants available to incinerate MSW amount is 200 thousand tons. Facility uses cogeneration processes to produce heat and electricity power to Kaunas region [10].

Bottom ash is a heterogeneous mixture of slag that contains glass and metal residues in varying proportions. Main chemical contents of bottom ash are silicon oxides and aluminium. Other compounds are from mineral origin, sulfates, chlorides, ferrous and non-ferrous metals and unburned organics. Elemental composition in bottom ash depends mainly by the source that is fed for incineration and type of combustion system. Bottom ashes tends to have high concentrations of heavy metals, which are very toxic environmental pollutants.

Within the Ministry of Environment of the Republic of Lithuania there has been made a new legislative project document, regarding bottom ash and slag treatment and handling process environmental protection requirements. Kaunas waste incineration plant is especially effected by this document, as its main waste output is bottom ash and slag. With these new requirements non-hazardous waste of bottom ash and slag has to be kept from any natural effects (wind, precipitation), final metal residue concentrations may not exceed 5% of total waste mass, total organic carbon must not be higher than 3% and loss-on-ignition must be less than 6%. In the requirements it is also stated that heavy metal (arsen, lead, cadmium, copper, nickel, mercury, zink), chloride, sulfate and cyanide leached concentrations would not exceed determined limit values. Also after pretreatment processes bottom ash fractions have to meet all technical requirements, listed in the functional requirements for building elements for earth construction sites.

Kaunas WI plants bottom ash is treated with advanced dry recovery (ADR) dry separation technology. Worldwide, it is used to treat up to 5 million tons of MSWI bottom ash annually [6]. Using dry screens, magnets, wind sifters, eddy current separators and the ADR, the process separates ferrous and non-ferrous metals from the BA generating mineral fractions of different grain sizes (0–2 mm, 2–5 mm, 5–12 mm and 12–50 mm). No waste water or sludge is generated in the process [5].

The aim of the research study was to analyse Kaunas waste incineration plants bottom ash elemental and molecular composition using x-ray diffractions (XRD) and scanning electron microscopies energy-dispersive X-ray spectroscopies (SEM-EDS) analytical techniques. Also, it was important to investigate the bottom ash treatment process using ADR technology and possibilities of utilizing processed material in civil engineering and concrete products. For utilization possibility certain conditions have to be met and recovered mineral fractions chemical properties must not exceed established national limit values.

In XRD analysis of treated bottom ash from Kaunas MSWI plant, first samples most predominant mineral materials were barium bismuth lead oxide - 58,89 wt.% and quartz 30,92 wt.%. Other included calcium carbonate – 10,19 wt.%, potassium magnesium silicate – 2.72 wt.%. In another sample highest concentration was of calcium carbonate – 25,41 wt.%, silicon oxide – 22,49 wt.% and dolomite – 19,33 wt.%, magnetite – 16,21 wt.%. XRD analysis results are filled in Table 1.

Table 1.

XRD analysis of treated MSWI bottom ash, sample 1 and sample 2 results.

Sample 1						
Name of material	Quartz	Barium Bismuth Lead Oxide	Potassium Magnesium Silicate	Calcium Aluminum Oxide	Calcium Carbonate	
Material, elemental composition formula	SiO_2	$Ba(Bi_{0.55}Pb_{0.45})O_3$	K_2MgSiO_4	$CaAl_2O_4$	$CaCO_3$	
Concentration	0.309189	0.588879	-	-	0.101931	
Scale factor	0.253959	0.103409	0.0271903	0.0195162	0.0873079	
Figure of merit	56%	36%	28%	22%	41%	
Sample 2						
Name of material	Silicon Oxide	Dolomite	Calcium Carbonate	Magnetite	Gypsum, syn	Cristobalite
Material, elemental composition formula	SiO_2	$CaMg(CO_3)_2$	$CaCO_3$	Fe_3O_4	$CaSO_4$ 2 H_2O	SiO_2
Concentration	0.224902	0.193321	0.254137	0.162145	0.0796461	0.085848
Scale factor	0.77318	0.275376	0.27787	0.117117	0.155609	0.0615106
Figure of merit	57%	37%	36%	34%	34%	14%

Using SEM-EDS analytical technique treated BA samples elemental composition has been determined. In the first sample, most common elements included: oxygen, calcium, silicon, lead and platinum. In the second sample, predominant elements were: oxygen, calcium, iron, silicon, gold and aluminum. It is important to understand that SEM-EDS analytical techniques results are highly dependent on the position in which an electron beam hits the analyte. Treated MSWI bottom ash elemental composition are filled in Table 2.

Table 2.

Bottom ash elemental composition with SEM-EDS analytical technique.

Sample 1				Sample 2		
Element	wt. %	at. %		Element	wt. %	at. %
O	45.35	67.42		O	42.26	66.91
Ca	20.33	12.07		Ca	12.72	8.04
Si	11.28	9.55		Fe	12.58	5.71
Pb	4.53	0.52		Si	10.28	9.27
Pt	4.13	0.50		Au	8.63	1.11
Al	3.74	3.29		Al	3.92	3.68
Na	3.39	3.50		Tl	2.38	0.29
W	1.43	0.19		Hg	1.58	0.2
Co	1.33	0.54		Na	1.58	1.74
K	1.09	0.66		S	1.31	1.03
Cl	0.88	0.59		K	1.19	0.77
Mg	0.76	0.74		Mg	0.90	0.94
Au	0.88	0.07		Cr	0.21	0.10
Hg	0.76	0.06		Co	0.18	0.08
Cu	0.60	0.09		Ti	0.17	0.09
Ti	0.22	0.11		Cu	0.11	0.04
Mn	0.22	0.09				

Heavy metal leaching depends on the solvent of extraction, pH and also from solid and liquid matter ratio [7]. The leaching of hazardous substances from municipal solid waste incineration (MSWI) bottom ash (BA) has been studied in many different scales for several years [5]. Vilnius Gediminas Technical University has performed leaching tests of UAB ‘’FORTUM KLAIPĖDA” (Ltd.) waste incineration plants bottom ash. Research was carried in accordance with LST EN 12457 2: 2003 standard, a compliance test for leaching of granular waste materials and sludges, when liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm [13]. Main goal of the research study was to determine and clarify: MSWI bottom ash toxicity level, treatment and recycling possibilities. According to standard, 4mm diameter fraction of MSWI bottom ash is tested for leachability, because in many literatures it is stated that this material fraction is most likely to have toxic elements in its composition. Three different ash samples have been tested in the research: specially pretreated, mechanically separated with magnet for metal scraps and untreated MSWI bottom ash fractions. For leachability test deionized water (5< Ph <7,5) has been used, its electric conductivity – 0,5 mS/m. After eluates chemical composition elemental analysis, it was observed that leached elemental concentrations (iron and heavy metals) changes depending if bottom ash is pretreated beforehand. This depletion of MSWI bottom ash heavy metal concentration in pretreated fraction may be a result of elemental irons adsorption of heavy metals. Presumptions can be taken that after removing iron particles from bottom ash, heavy metals are also removed. The results showed that after the leaching test was performed the levels of other analytes of interest in the eluate did not exceed the limit values in accordance with the 1999/31/EC Directive for landfill non-hazardous waste [9].

Denmark, Sweden and Finland are good examples, how residual products from energy production can be used as a substitute for the materials such as sand and gravel. These northern Europe countries Ministries of Environment have issued a legalization that regulates the handling of this type of materials. The legalization is intended to be a specialized instrument, which simplifies the administration of recycling [11]. Furthermore, the legal document lays out the designated projects rules and limitations based on treated bottom ashes analyses. Swedish and Finnish Mara-act promotes recovery of waste by specifying the conditions under which, if fulfilled, the use of treated bottom ash fractions would not require an environmental permit. By closely monitoring ash leachability for harmful substances and deciding at what conditions and in what areas it can be used, responsible recycling of waste has been achieved. With advanced technology mineral bottom ash fraction can be utilized in construction and concrete products. Examples of recycling include: field and road structures, paving stones, modular bricks for making noise walls, support walls, waste sorting points, and various other storage solutions.

In the following research of Kaunas waste incineration plants bottom ash, using XRD and SEM-EDS methods, it was investigated 4 different treated wastes granulometric fractions elemental and mineralogical composition. Treated bottom ash fractions moisture contents determination at different conditions. Leachability tests by water and other solvents to determine leached harmful substance concentrations, will also be included. Based on performed results using XRD analysis, bottom ash fractions most dominant minerals were: silicone dioxide, dolomite, barium bismuth lead oxide and calcium carbonate. SEM-EDS methods analysis for elemental composition revealed that treated bottom ash has the highest elemental concentrations of oxygen, silicon, calcium and iron. Smaller concentrations were found of non-ferrous metals and elements such as: potassium, magnesium, sulfur and chloride. Northern Europe countries experience suggests that after thoughtful regulation of Kaunas waste incineration plants treated with bottom ash, this waste can be safely recycled for constructions and concrete products.

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