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ASPECTS REGARDING THE STABILIZATION OF RESIDUES RESULTING FROM WASTE INCINERATION

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Abstract: In this paper are presented the methods of stabilizing the residues resulting from waste incineration. The main components which pollute the environment and human health that are found in this type of waste are: heavy metals: Cd, Cr, Cu, Ni, Pb and Zn, dioxins. Residue treatments are needed to reduce the impact on the environment. The methods of separating the contaminants from the waste incineration residues presented in the paper are: separation by water use, separation by acid use, separation by the use of microorganisms, separation by electrodialysis. The methods of heat treatment of residues from waste incineration are: vitrification, smelting, sintering, pyrolysis, physical and chemical separation. Methods of chemical stabilization of contaminants from waste incineration are performed with: iron oxides, carbon dioxide and phosphoric acid, using phosphate as a stabilizing agent, which binds heavy metals in the form of phosphate minerals, stabilization using sulfur that binds heavy metals into insoluble compounds. Heat treatments reduce the volume of waste by 60% or more to almost 95%.
Keywords: stabilization, solidification, vitrification, incineration, sintering, pyrolysis

INTRODUCTION

The development of the economy and urbanization have led to an increase in the quantities of solid waste generated, opting for their heat treatment processes through incineration units. This method of waste treatment has also grown due to the filling up to maximum capacity of existing landfills, requiring the creation of new landfills that negatively influence the quality of air, water and public health (Gong, B., et al, 2017).

The composition of industrial waste varies, including in this category hazardous waste that is usually loaded with heavy metals toxic to environmental factors, such as Cd, Cu, Cr, As, Pb (Nicolae, A., et al, 2020). Heavy metals are not biodegradable and tend to accumulate in living organisms and affect environmental factors, requiring the application of treatments to eliminate and capture them.

Waste incineration is an alternative method of waste management (Ioana, A., et al, 2016; Ţucureanu, M., et al, 2019). Due to the capacity of the waste reduction process, waste incineration has advanced in the face of waste disposal. However, the waste incineration process generates residues that are mainly divided into fly ash and bottom ash (Gong, B. et al, 2017).

An integrated part of waste management systems is the management of waste from their heat treatment. The main purpose of the management of waste incineration is to prevent any impact on human health or the environment which is characterized by emissions of particulate matter or emissions of substances (Sabbas, T., et al, 2003).

Fly ash resulting from the waste incineration process is a dangerous by–product because it contains heavy metals such as Cd, Zn, Pb, Hg, Cu, Cr, etc., and the readability of these heavy metals is outside the regulations in most cases (Gong, B. et al, 2017).

Due to these harmful compounds found in the resulting residues, their stabilization treatments are used such as thermal processes, stabilization / solidification processes and separation processes.

The washing process can separate a large proportion of heavy metals and soluble salts contained in the residues resulting from the waste incineration process. In this treatment a liquid base such as water or an aqueous acid solution is used, reducing the concentrations of chloride and heavy metals. The reduction of the concentrations of heavy metals and chlorides is not significant, hardly complying with the regulations of the legislation in force, being necessary the application of other treatments (Gong, B. et al, 2017).

Washing with acid–based solutions is more efficient for removing heavy metals from bottom residues compared to washing them with plain water. Regardless of the liquid used for washing, the wastewater used in this process captures heavy metals and soluble salts, thus creating a secondary source of pollution (Gong, B., et al, 2017).

Stabilization / solidification treatments are the most common techniques in waste treatment, in the treatment of residues from waste incineration, this treatment manages to limit the leakage capacity of heavy metals by forming constant blocks or inert compounds by adding additives or binders (Gong, B. et al, 2017).

This type of treatment comprises the following steps: solidification, stabilization, hydration and precipitation reactions. The solidification step is a process for mixing the residues with liquid following the solidification of the suspension.

Heat treatment of stabilization of residues is a promising method for fixing heavy metals by heating the residues to very high temperatures between 700–1600°C. This type of treatment is characterized by vitrification, sintering and melting of solidified residues (Gong, B., et al, 2017). As hazardous waste, the residues from the control of air pollution are most often stored in special landfills without taking into account their recovery (Lam Charles, et al, 2010; Bacinschi, Z. et al, 2010; Purdea, L., et al, 2019; Rusănescu, CO, et al, 2019).

All treatments for waste incineration developed in recent years are based on principles such as changing their character from hazardous to non–hazardous and even inert, (Lam Charles, et al, 2010). Residues of solid, liquid or gaseous nature result from the waste incineration process. The volume of these residues represents about one tenth of the initial volume of waste (Sabbas, T., et al, 2003). The residues resulting from incineration are: bottom ash, ash resulting from the boiler and economizer, residues from the control of air pollution, fly ash, residues from the sieving area of the grate.

MATERIALS AND METHODS

Figure 1 shows the methods for treating waste from incineration of waste.

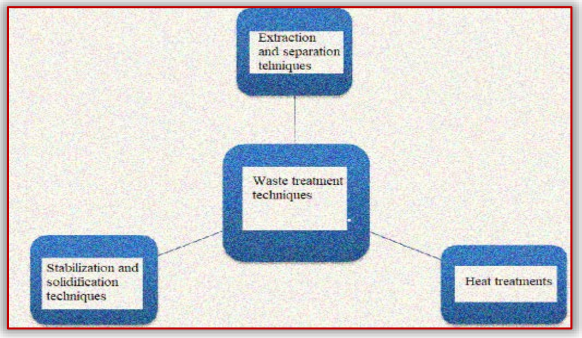

Figure 1 – Waste incineration techniques

The methods for separating contaminants from waste incineration waste are:

Separation by the use of water, the mixing of water with the residues resulting from the incineration of waste results in the formation of an alkaline suspension characterized by a pH with a value close to 11–13 but also with high concentrations of salts such as Cl, Na. The suspension also contains heavy metals such as Pb, Zn, Cr and As.

Separation using acid, acidic solutions extract the salts present in the residue. Due to the solubility of heavy metals at lower pH values, the use of acid is more efficient for heavy metals in the residue, so the acid is more efficient than water. About 30–60% of the cationic heavy metal content can be removed from the residues using acid.

Separation by the use of microorganisms The processes known as bio–hydrometallurgical processes are based on the bio–absorption process, a process of physico–chemical interaction between groups of surfaces charged by microorganisms and ions in solution, in which both living organisms and the dead. In this regard, a multitude of microorganisms are known, including those such as algae, bacteria, yeasts and fungi, which can accumulate active gold, (Schaeffer, N., et al, 2018). Bio–hydrometallurgy is a process used to recover metals from solid materials such as low–grade ores.

Separation by electrodialysis Metals can be extracted by applying a stream, thus facilitating the migration of ions in a residue suspension to an anode or cathode. Ion exchange membranes can be subsequently used to separate metal ions from the suspension of treated residues, (Astrup, T., et al, 2009).

The technique requires that the metals be in the aqueous phase and the release from the solid can be optimized by resorting to complexing agents (Astrup, T., et al, 2009).

This process involves two stages and it is necessary to extract the metals in the first stage through the use of water and then apply the second stage of the separation process by electrodialysis (Astrup, T., et al, 2009).

The removal rate of metals is about 20–70% for metals such as Zn at a ratio of 5 liters of water per kilogram of residue, (Astrup, T., et al, 2009). The efficiency of metal extraction from the mixture is also due to the intensity of homogenization.

The methods of heat treatment of residues from waste incineration are: (Astrup, T., et al, 2009).

- Vitrification involves melting a mixture of glass residues and precursors such as silicon at temperatures between 1000–1500°C. In this process, the components of the residues are bonded into the glass materials, thus encapsulating the residues. The materials used to form the glass could be other types of mineral waste, the properties of the final product depending to a large extent on the additives used (Sabbasa, T., et al, 2003).
- Melting the resulting material consists of several metal phases. Process temperatures are similar to the temperatures used during vitrification, vitrification processes as well as melting processes are most often applied to residues such as bottom ash. The melting processes are similar to those of vitrification, in which case no additives are added to form the glass.
- Sintering involves heating to a stage at which the individual particles are attached to each other. The sintering of the residues was mainly used for the bottom ash, the process often involving the reintroduction of the residues in the incinerator. The temperatures at which the sintering process is performed are around 900–1300˚C producing a denser and less porous material.
- Pyrolysis is most often used for organic waste in combination with incineration residues. The residue components are then heated to high temperatures and mixed with the other products introduced into the pyrolysis process. The characteristics of the products resulting from the process of pyrolysis depend to a large extent on the waste with which the residues were mixed.

RESULTS

The main components harmful to the environment and human health found in waste are:

- Slightly soluble salts, such as Cl and Na salts;
- Heavy metals: Cd, Cr, Cu, Ni, Pb and Zn.
- Dioxins (Ahamed, A. et al, 2021).

Residue treatments are needed to reduce the impact on the environment due to the release of contaminants. The elimination of these risks can be done by binding them in the residue matrix and by removing them (Țucureanu, M., et al, 2019).

Bottom ash is a slag–like residue collected from the combustion chamber (Hyks Jiri, et al, 2011). Table 1 shows the concentrations of the elements found in bottom ash, fly ash and in semi–dry residues from an industrial waste unit (Hyks Jiri, et al, 2011).

Table 1. Chemical composition of residues from high capacity incineration plants

Element		Bottom ash	Semi–dry residues	Flying ash
Dry substance	[%]	84.9 – 97.9	95.3	98.8
Ca	[g/kg]	96.5 – 108	331	181
S	[g/kg]	3.5 – 5.6	35	57
Al	[g/kg]	39.1 – 65.6	18.3	35.7
Si	[g/kg]	198 – 248	63	90
Na	[g/kg]	23.2 – 29.4	16	42.3
K	[g/kg]	8.8 – 11.6	17.1	50
Cl	[g/kg]	3.0 – 9.0	17	122
Mg	[g/kg]	10.0 – 13.1	7.8	14.1
Fe	[g/kg]	79.9 – 100	9.7	13.8
As	[g/kg]	25.0 – 45.2	80	380
Ba	[g/kg]	1360 – 1750	620	1120
Cd	[g/kg]	2.6 – 3.7	100	240
Co	[g/kg]	20.4 – 26.2	8.9	20.9
Cr	[g/kg]	434 – 914	200	700
Cu	[g/kg]	2060 – 14300	500	1170
Mo	[g/kg]	7.62 – 20.1	9	28
Ni	[g/kg]	242 – 526	37.5	67.4
Pb	[g/kg]	1080 – 3530	2100	6800
Sr	[g/kg]	311 – 634	500	400
V	[g/kg]	40.7 – 59.3	19,8	39.7
Zn	[g/kg]	2660 – 4230	9100	31700
Sb	[g/kg]	51.4 – 105	340	1170
P	[g/kg]	3779 – 5237	3400	10000
Toc	[g/kg]	14.0 – 19.0	2,7	0.7

TOC – total organic carbon

Table 2. Treatments applicable to residues from the incineration of waste

Types of treatments applicable to residues	
Basic principle of treatment	Process
Physical and chemical separation	Dimensional separation
	Mechanical separation
	Eddy–Current separation
	Wash
	Chemical extraction
	Chemical precipitation
	Ion exchange
	Adsorption
	Crystallization / evaporation
Solidification and / or stabilization	Solidification / stabilization with hydraulic binders
	Chemical stabilization
	Aging / precipitation
Thermal treatment	Sintering
	Vitrification
	Melting

Bottom ash untreated is a heterogeneous material, consisting of calcium–rich minerals and silicate. In large incineration plants most of the bottom ash consists of molten products such as glass, iron, bones and all kinds of minerals, heavy metal contamination is low (Hyks Jiri, et al, 2011). The treatment of waste from incineration of waste must be considered an integral part of any management, use and neutralization option. A variety of treatment options for waste incineration residues have been developed for application before reuse or final disposal depending on the purpose of the waste use (Sabbasa T, et al, 2003). Table 2 shows the treatments applied to the incineration residues.

— Physical and chemical separation

The purpose of the separation methods is to improve the quality of the waste from the incineration of waste and to optimize its capacity. These techniques include processes such as: washing, leaching, electrochemical process and heat treatment, (Lam Charles, et al, 2010). The main action of these processes is based on the removal of heavy metals and salts from residues, mainly using water or acidic solutions (Astrup, T., et al, 2009).

— Solidification and stabilization

The solidification / stabilization process uses an additive or binder to chemically and / or physically fix the hazardous content in the residues. Stabilization aims to minimize the solubility and toxicity of contaminants. In the case of solidification, binders used such as cement aim to encapsulate residual materials, to immobilize contaminants and reduce readability (Lam Charles, et al, 2010).

The methods of chemical stabilization of residue contaminants from waste incineration are:

- The addition of iron oxides ($FeSO_4$) to a residue suspension can increase the absorption capacity of heavy metals (Astrup, T. et al, 2009). This technique involves several steps: the first step involves the extraction of water, slightly soluble salts and mixing with iron sulphate. The second stage comprises the oxidation of iron to form the precipitation of iron oxides, the adjustment of the pH to a value of about 10–11 and the dehydration of the residue.
- Stabilization with carbon dioxide and phosphoric acid binds metals such as carbonates or relatively insoluble phosphates. Phosphate stabilization as a stabilizing agent binds heavy metals in the form of phosphate minerals.
- Sulfur stabilization binds heavy metals into insoluble compounds. This technique is regularly used to treat process wastewater and residues. This process using sulfur is recommended in the case of flue gas cleaning installations. The residual sludge contains inactivated sulfur compounds that mixed with the residues can improve the leakage properties of the final product.

The latest integrated stabilization process comprises four stages, (Lam Charles, et al, 2010): removal of alkaline chlorides by dissolution; phosphoric acid additions; calcination; solidification with cement. This combined process destroys toxic organic compounds, reduces the reactivity of heavy metals and solidifies hazardous compounds without exceeding the leaching limit, (Lam Charles, et al, 2010).

Applying a combined wash–immobilization treatment to treat fly ash could remove significant amounts of chloride and sulfate and turn heavy metals into less reactive forms. At the end of the washing process, the wastewater used in this process can be treated by reducing the pH to 6.5–7.5 (Lam Charles, et al, 2010).

Solidification processes are based on processes whose purpose is to physically and hydraulically encapsulate residues and their harmful compounds.

A process of chemical stabilization involves the precipitation of insoluble compounds that incorporate metals into their composition. The use of treatments based on hydraulic or chemical binders positively influences the mechanical properties of the material (Sabbasa, T. et al, 2003).

The aging and precipitation processes are used in order to alter the physico–chemical properties of the minerals, thus reducing the trace elements such as Cd, Cu, Pb, Zn and Mo. These processes can influence the decrease of pH and contamination but also the formation of more stable mineral species. These types of processes can be applied especially to the bottom ash. After completion of the material resulting from the treatment of bottom ash, it is necessary to store it before use for periods of weeks or months. Aging and precipitation treatments can be artificially improved to accelerate the chemical reactions responsible for filtering contaminants from the waste matrix, thus using accelerated carbonation to reduce the flow of soluble salts, lead and zinc, (Sabbasa, T., et al, 2003).

— Heat treatments

The heat treatment process can reduce the volume of waste by 60% or more to almost 95%. The resulting residue is more resistant to leaching and is more environmentally stable, becoming an optimal material for applications such as use as a raw material in the construction industry. A temperature of about 1,400°C or higher will destroy dioxins, furans and other toxic organic compounds that can be found in the residue. Due to the high temperatures used in the process, the cost is usually high, and the release of contaminants during melting is possible requiring additional control of air pollution, (Lam Charles, et al, 2003). Combined treatment methods aim at the following (Sabbasa, T. et al, 2003):

≡ decontamination of ferrous metal residue;
≡ decontamination of non–ferrous metal residue;
≡ decontamination of the salt residue;
≡ optimization of the physical properties of the residue;
≡ optimization of the chemical properties of the residue;
≡ optimization of the mechanical properties of the residue;
≡ decontamination of the residue in order to recover it in different applications.

CONCLUSIONS

Progress has been made in recent years on integrated waste management systems. Waste treatment technology, the reduction of landfills and the recovery of waste from incineration of waste have become integrated methods of these systems. With the development of incineration lines and the appearance of more waste, the problem of pollution caused by them began to appear. These pollutants are characterized by heavy metals, salts from washing waters, or other forms of emissions. Residue treatments have been developed to reduce the risks to the environment and human health. The overall strategy that any country must take into account must be to reduce environmental pollution.

Many of the applications for waste incineration waste are still being researched and environmental and technical issues have discouraged their reuse. Even if waste treatment increases the total cost of the waste neutralization process, the benefits of recovering it are beginning to be widely observed. For residues containing significant amounts of contamination, treatment is recommended in order to reduce the rate of contamination into soil or water.

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