Vojka Gardić, Ljubiša Obradović*, Sandra Filipović**

REVIEW OF SOLIDIFICATION AND STABILIZATION METHODS OF HAZARDOUS WASTE**

Abstract

The paper presents stabilization and solidification (S/S) methods of hazardous waste, depending on the type of waste and content of hazardous and harmful components as the pretreatment method of hazardous waste prior to disposal on landfills. Also, the paper presents the impact of selected additives and the aging conditions of the process product on the effectiveness of the S/S processes. Process efficiency was measured by mobility of hazardous and harmful components. Representation of some processes of stabilization and solidification in the pretreatment of hazardous waste prior to disposal in the world are shown. The aim of this paper is systematization of data and selection of optimal Solidification/Stabilization process for further research in the field of reduction the impact of mining waste on the environment.

Keywords: stabilization, solidification, hazardous waste treatment

INTRODUCTION

Stabilization/solidification (S/S) is a technique that uses physical and chemical properties of cementitious binders or chemical transformation to integrate trace elements from waste, whose disposal is prohibited without pretreatment.

Solidification and stabilization are generic names that are applied to a wide range of technologies that are closely related to the chemical and/or physical processes to reduce the potential negative environmental impact by disposal of radioactive, hazardous and mixed waste on landfills without pretreatment [1, 2, 3].

Stabilization is the chemical process of reduction the hazardous characteristics of waste. The hazardous component transforms

from less soluble form and/or a form which is less toxic.

In situ stabilization is the well-known method for immobilization of contaminants, which prevents further spreading of pollution through soil and groundwater. The most common method of in situ stabilization involves mixing of contaminated soil or waste with cement or other materials that have similar chemical and physical properties (fly ash...). The chemical and physical properties of cement or other materials include the adsorption ability and ability to reduce the mobility of hazardous and harmful component.

Solidification is the process/operation that transforms hazardous waste into a solid

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form using the additives and does not necessarily involve the chemical reaction between additives and solidification of hazardous waste.

Depending on granulation of material which will be treated, solidification is divided into micro-encapsulation and macro-encapsulation solidification [4].

Solidification is applied on tailing dumps, where solids are mixed with additives, and as the result of mixing emerging geopolymeric matrix (soil cement). After adjusting the mixing ratio, the mixture forms a solid monolithic layer.

S/S is a very important process which allows transformation of waste into inert material, independently of solubility value of each individual metal, or components in the waste. Also, the great importance fact is that some physical or chemical parameters (permeability, compression strength) can be easily controlled by selection of chemical additives and its ratio in mixture (waste/additive).

The strength of solidification process product has a direct influence on the process efficiency and can be increased by reduction the water ratio in mixture, increasing the solidification temperature or increasing of calcium chloride or Portland cement ratio as an additive.

Fly ash is a good replacement to Portland cement from an economic point of view, and its use has reduced the use of Portland cement in the industry by 25 to 55% [5].

The S/S process is primarily designed for treatment of hazardous waste (including radioactive waste). The effectiveness of S/S process is reflected in a significant reduction of negative impact of deposited (hazardous) waste on the environment (soil, surface water, groundwater) and indirectly on flora, fauna and human health.

This paper presents the results of previous research the application of S/S processes on different types of waste. Also, the efficiency of additives, depending on the ratio and type of waste, is shown. The aim of

paper is to systematized data for better choice of optimal Solidification/Stabilization process for further research and application in the field of reduction the impact of mining waste on the environment.

RESULTS AND DISCUSSION

Efficiency of Additive According to the Type of Waste

Treatment of sludge and waste with high content of liquid phase. The S/S process is applied on liquid waste, or waste with high content of liquid phase, whose disposal in landfills without prior treatment is not possible. In such cases, the cement is used as a binding additive because the water reaction with the cement produces the hydrated cement by chemically binding. Compression strength of at least 0.34 MPa (50 psi) is evidence that treatment of the free liquid phase often comes due to the chemical bonds between the liquid phase and cement, the liquid phase becomes less likely adsorbed [5].

Treatment of waste with inorganic pollutants content mostly. The most common application of S/S process is treatment of inorganic materials contaminated with hazardous components. Inorganic materials contaminated with heavy metals are often categorized as hazardous due to the increased leaching potential of heavy metals (leaching test) and showing the toxic characteristics (toxicity test). Treatment of waste by solidification or stabilization process results into reducing the mobility of heavy metals and reducing the leaching potential of inorganic material. After pretreatment, the material does not show hazardous characteristics and can be disposed of nonhazardous waste landfill. In the case of implementation the remediation process as the sustainability of the land, S/S process is often the only solution of available technologies for remediation of large amounts of contaminated soil with heavy metals, sludge or sediment. As an additive, in this case the cement is recommended because it reduces the mobili

ty of the metal ions, forming less soluble metal hydroxide, carbonate or silicate. During the S/S process metal from waste can be transformed from ionic form in the mineral structure and physical encapsulation. Furthermore, pretreatment may reduce the toxicity of metal by change in the valence [5].

Treatment of waste with organic pollutants content mostly. Remediation of materials containing mainly organic pollutants is possible applying a cement additive. During the S/S process the material cures by changing the physical properties of cement. In particular, it is recommended, if the waste is with high content of free water, which enters the process of hydration, the cement material creating a highly integrated physical monolith.

The S/S method has shown high efficiency in reducing the mobility of hazardous and harmful substances from the waste of content of halogenated semi-volatile polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, organic cyanide and etc.

Disadvantage of cement is inefficient application on waste treatment with high content of fats and oils, when hydration process of cement is not possible. Cement particles are coated with oil or grease, which do

not allow contact between cement and water. Some organic compounds influence on the curing time of the cement, whereby the whole process of solidification can be considerably extended. Due to these reasons, it is necessary to do a complete qualitative and quantitative analysis, before the selection of additives. Also, the use of calcium carbonate results into occurrence of exothermic reaction during the process of hydration with simultaneously emission a significant amount of energy. If the waste consists of significant quantities of volatile hazardous and harmful components, the same will be emitted into atmosphere during the S/S. If there is no other alternative to lime as an additive in the S/S process, it is necessary to provide the facilities for collection and treatment of waste gas [5].

Treatment of waste with content of heavy metals – Applying the both procedures of stabilization and solidification on wastes with content of heavy metals it comes to largely transformation forms of heavy metals (mostly in the form of less soluble hydroxide) and mobility of ions of heavy metals is reduced.

Solidification and stabilization of heavy metals by hydrates of Portland cement is shown in Figure 1.

Figure 1 Solidification and stabilization of heavy metals by hydrates of Portland cement [6]

Preferred S/S methods depending on the type of waste are shown in Table 1 [7].

Table 1 Preferred S/S methods depending on the type of waste

Type of S/S method	Application
Solidification with cement additive	Sludges, contaminated soil
Solidification process with lime additive	Some inorganic wastes, waste from desulphurization treatment of wastes gases
Solidification with thermoplastic materials	Radioactive waste
Encapsulation	Sludges, liquids, some particular materials
Vitrification	Radioactive waste, extremely hazardous waste

Model for Additive Selection Depending on the Type of Waste

The model of waste, selected to represent the neutralization precipitates was an ochreous mine water waste (OMW-fine-grained, Fe- and Ca-rich neutralization precipitates from bioleaching with relatively low levels of hazardous components) and an industrial jarosite residue (JR - with higher levels of hazardous com-

ponents). Silica sand (SS) was used as the bulk mineral material in the CLSM formulations. A commercially available cement (PC), PFA and Lime (L) were used as binder. Test results of stabilization of hazardous wastes with different content of hazardous components using different additives are shown in table 2 [8].

Table 2 Test results of stabilization the hazardous waste with different content of hazardous components using different additives

Mix	% Dry solids						Ratio of water to solid
	PC	FA	SS	OMW	JR	L	
5PC-FA	5	15	80	-	-	-	0.20
5PC-FA-OMW	5	15	70	10	-	-	0.30
5PC-FA-JR	5	15	70	-	10	-	0.25
10PC-FA-JR	10	15	65	-	10	-	0.30
10L-FA-JR	-	15	65	-	10	10	0.43
5PC-FA-L-JR	5	15	65	-	10	5	0.41

Concentrations of heavy elements As, Cd, Co, Cu, Mn, Mo and Ni were below limit values, even from specimens containing jarosite waste having elevated levels of these elements. Adsorption onto hydrated iron (III) oxide abundant in the specimens accounted for the low mobility of arsenate. The metals should also be adsorbed, aided in most cases by low solu-

bility at high pH prevalent in lime and cement.

However, cationic Ba exceeded limits for all specimens (including the cement/fly ash control) and amphoteric Cr, Pb and Zn gave excessive concentrations for some formulations, particularly with jarosite.

Results of investigation the opportunities, applying different additives (lime,

UFS - foundry sand from US Steel Balkan - Stara Zelezara d.o.o) for waste stabilization process and chemical analysis of leaching solution after treatment the solid samples with different additives after 4

cycles, are presented in Table 3. The treated waste samples are from Bor area generated during mining activities with increasing content of copper (0.12%), iron (4.06%), lead (0.07 %) and zinc (0.07 %) [9].

Table 3 Heavy metal mobility after treatment the solid samples with different additives after 4 cycles

Mixture	Metal	mg/L			
		1	2	3	4
Dam 3 A	Cu	11.8	11.6	10.8	10.8
	Fe	8.1	4.4	6.5	4.3
	Pb	<1	<1	<1	<1
	Zn	5.2	5.1	6.6	5.9
Dam 3 A + (100% lime)	Cu	0.24	0.21	0.27	0.27
	Fe	<0.05	<0.05	<0.05	<0.05
	Pb	<1	<1	<1	<1
	Zn	0.34	<1	<1	<1
Dam 3 A + (100% UFS)	Cu	12.93	16.14	18.44	16.98
	Fe	7.395	5.882	2.689	2.857
	Pb	<1	<1	<1	<1
	Zn	11.19	13.19	13.79	13.15
Dam 3 A + (90% UFS + 10% lime)	Cu	n.d	n.d	n.d	0.077
	Fe	0.336	0.336	0.336	0.336
	Pb	0.714	0.714	0.714	0.714
	Zn	0.128	0.085	0.128	0.255
Dam 3 A + (75% UFS + 25% lime)	Cu	n.d	0.077	n.d	n.d
	Fe	0.336	0.336	0.504	0.336
	Pb	n.d	n.d	n.d	n.d
	Zn	0.213	0.043	0.085	0.170

The best results were obtained using the lime as an additive, as might be expected, because it is an inorganic waste with high content of heavy metals.

Factors Affecting the Stabilization and Solidification Efficiency

Proper selection of reagents. Stabilization of waste generated as the result of mining activity with high content of aqueous phase. Lime neutralization is the most common method which is recommended for

stabilization the hazardous waste, particularly the inorganic waste with content of heavy metals, which is confirmed by research of M. Korać et al. [9]. In addition, in the process of solidification, at the surface of the grains, in the presence of silicon and aluminum, a liquid barrier calcium silicate gel or calcium-aluminate gel can occur, there by increasing the efficiency of process [10].

Metal hydrolysis solubility curve is shown in Figure 2, the influence of pH value on heavy metal mobility can be also seen [5].

Figure 2 Metal hydrolysis solubility curve

Aging time of stabilization and solidification product - Posttreatment of resulting product of solidification and stabilization process may have a significant effect on efficiency of waste treatment procedures. The aging conditions and aging time are the parameters that should be

investigated. Relationship between metal mobility and sludge aging is shown in Figure 3.

The aging time about 6 month at temperature about 25°C, in atmospheric conditions, decrease mobility of hazardous components from sludge less than 10 mg/L [5].

Figure 3 Relationship between metal mobility and sludge aging

Application of solidification and stabilization process in hazardous waste treat

ment before disposal on landfill is shown in Figure 4 [11].

Figure 4 Application of solidification and stabilization process in hazardous waste treatment before disposal on landfill

CONCLUSIONS

The aim of application the solidification is to change the physical character of waste and prevent formation of large quantities of leachate on landfills, with high content of hazardous and harmful components, which results in a double effect, protect the environment, and on the other side reduce the economic effect of disposal process of hazardous waste as there is no need for installation and operation the systems for wastewater/leachate from the landfill. The selection of stabilization and solidification process, i.e. additives is one of the key elements that most affect the efficiency of the applied treatment. Due to this reason, the most important step in stabilization and solidification the waste materials is a qualitative and quan

titative analysis of waste material. Based on that, it can make selection additives for the S/S process. It is necessary to investigate the impact of aging time and aging conditions resulting product S/S processes on the mobility of hazardous and harmful components of waste, thus making it possible to increase the effectiveness of the pretreatment.

S/S processes shall not be applied on waste containing volatile organic compounds, because during the S/S process the emission of significant amount of energy and emission of volatile hazardous and harmful components into atmosphere can occur. If there is no other alternative for this process, it is necessary to provide the facilities for collection and treatment of waste gas.

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PREGLED METODA SOLIDIFIKACIJE I STABILIZACIJE OPASNOG OTPADA**

Izvod

U radu su prikazane metode stabilizacije i solidifikacije (S/S) opasnog otpada u zavisnosti od vrste otpada i sadržaja opasnih i štetnih komponenti, kao metoda predtretmana opasnog otpada pre odlaganja na deponiju. Prikazan je uticaj aditiva na efikasnost procesa S/S u zavisnosti od vrste otpada, uslova starenja produkta procesa S/S. Efikasnost S/S procesa merena je mobilnošću opasnih i štetnih komponenti nakon postupka solidifikacije/stabilizacije. Prikazana je i zastupljenost pojedinih postupaka stabilizacije i solidifikacije u procesu predtretmana opasnog otpada pre odlaganja. U radu su sistematizovani podaci vezani za procese stabilizacije i solidifikacije sa ciljem izbora najoptimalnijeg procesa za dalja istraživanja u oblasti smanjenja uticaja otpada nastlog kao posledica rudarskih aktivnosti na životnu sredinu.

Ključne reči: stabilizacija, solidifikacija, opasan otpad, tretman.

UVOD

Stabilizacija/solidifikacija (S/S) su procesi u kome se primenom fizičkih i hemijskih osobina cementnih veziva ili hemijskom transformacijom uz pomoć aditiva smanjuje mobilnost opasnih i štetnih supstanci iz otpada, čije je deponovanje bez predtretmana zabranjeno.

Solidifikacija i stabilizacija su procesi koji obuhvataju širok spektar tehnologija, koje su usko povezane sa hemijskim i/ili fizičkim procesima smanjenja potencijalnih negativnih uticaja na životnu sredinu odlaganjem radioaktivnog, opasnog ili mešovitog otpada na zemlju, bez predtretmana [1, 2, 3].

Stabilizacija je proces pri kome se primenom hemijskih postupaka smanjuju karakteristike otpada/materijala koje ga čine

opasnim. Procesom stabilizacije opasna komponenta se transformiše u manje rastvorni oblik i/ili oblik koji je manje toksičan.

In situ stabilizacija je poznata metoda za imobilizaciju zagađivača, kojom se sprečava dalje širenje zagađenja kroz zemljište i podzemne vode. Najzastupljenija in situ metoda stabilizacije podrazumeva mešanje kontaminiranog zemljišta ili otpada sa cementom kao aditivom ili drugim materijalima koji imaju slične hemijske i fizičke osobine (lebdeći pepeo), što podrazumeva sposobnost adsorpcije i smanjenje pokretljivosti opasnih i štetnih komponenti.

Solidifikacija je proces/operacija kojom se opasan otpad, primenom aditiva tranfor-

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miše u čvrstu formu i ne uključuje nužno hemijsku reakciju između aditiva i opasnog otpada koji se solidifikuje. Solidifikacija se deli na mikroenkapsulaciju i makroenkapsulaciju u zavisnosti od granulacije materijala koji se tretira [4].

Solidifikacija se primenjuje na jalovštima, gde se čvrste materije mešaju sa aditivima, a kao rezultat mešanja nastajanje geopolimerne matrice (zemljišni cement). Nakon podešavanja odnosa mešanja, mešavina formira čvrsti monolitni sloj.

S/S je važan tehnološki postupak koji omogućava transformaciju otpada u inertni materijal, nezavisno od pojedinačnih vrednosti rastvorljivosti metala, odnosno komponente u otpadu. Takođe je od velike važnosti činjenica da se neki fizički ili hemijski parametri (propustljivost, otpor na kompresiju) mogu lako kontrolisati izborom hemijskog aditiva i njegovog udela u mešavini (otpad/aditiv).

Čvrstoća proizvoda procesa solidifikacije ima direktan uticaj na efikasnost procesa i može se povećati smanjenjem udela vode, povećanjem temperature na kojoj se odvija proces očvršćavanja ili povećanjem udela kalcijum hlorida ili Portland cementa kao aditiva.

Leteći pepeo je sa ekonomske tačke dobra alternativa Portland cementu jer smanjuje njegovu upotrebu za 25 do 55%. [5].

Proces S/S namenjen je prvenstveno za tretman opasnog otpada (uključujući i radioaktivni otpad). Efikasnost S/S procesa ogleda se u znatnom umanjenju negativnog uticaja deponovanog (opasnog) otpada na životnu sredinu (zemljište, površinske vode, podzemne vode) i posredno na živi svet i zdravlje ljudi.

U radu su prikazani rezultati prethodnih istraživanja u smislu mogućnosti primene procesa S/S na različite vrste otpada, efikasnost aditiva u zavisnosti od udela i vrste otpada. Osnovni cilj je sistematizacija podataka i izbor najoptimalnijeg procesa solidifikacije/stabilizacije za dalja istraživanja u oblasti smanjenja uticaja otpada nastlog kao

posledica rudarskih aktivnosti na životnu sredinu.

REZULTATI I DISKUSIJA

Efikasnost aditiva u zavisnosti od vrste otpada

Tretman otpadnih muljeva i otpada sa velikim sadržajem tečne faze. Proces S/S nalazi opravdanu primenu kod otpada u tečnom stanju ili otpada sa velikim sadržajem tečne faze, čije odlaganje na deponije bez prethodnog tretmana nije moguće. U ovakvim slučajevima efikasna je primena cementa kao aditiva za vezivanje tečne faze, jer cement reaguje sa vodom, hemijski vezujući vodu u hidratizirani cementni proizvod. Otpor na kompresiju od najmanje 0,34 MPa (50 psi) je dokaz da tretiranjem slobodne tečne faze na pomenuti način dolazi češće do vezivanja tečne faze hemijskim vezama, ređe tečna faza biva adsorbovana [5].

Tretman otpada sa sadržajem pretežno neorganskih zagađivača. Najčešća primena S/S procesa je primena na materijalima kontaminiranih neorganskim opasnim komponentama. Generalno, za neorganski – kontaminirane materijala, opasnost leži u sadržaju teških metala. Neorganski materijali kontaminirani teškim metalima često se kategorišu kao opasni zbog povećanog lužnog potencijala teških metala (test lužljivosti) i ispoljavanja toksičnih karakteristika (test toksičnosti). Procesom S/S dolazi do smanjenja mobilnosti teških metala i smanjenja lužnog potencijala neorganskog materijala. Posle predtretmana, materijal ne ispoljava opasne karakteristike i može se odlagati na deponiju neopasnog otpada. U slučaju sprovođenja remedijacije, kao postupka održivosti zemljišta, S/S je često jedino rešenje i dostupna tehnologija za remedijaciju velike količine zemljišta kontaminirane teškim metalima, mulja ili taloga. Kao aditiv se u ovom slučaju preporučuje cement, jer smanjuje mobilnost

metalnih jona, formiranjem teškoraštvoernih hidroksida metala, karbonata ili silikata. U toku procesa S/S dolazi do prelaska metala iz jonskog oblika u mineralnu strukturu i fizičke enkapsulacije. Takođe, predtretmanom se može smanjiti toksičnost nekih metala promenom valentnog stanja [5].

Tretman otpada sa sadržajem pretežno organskih zagađivača. Tretman materijala sa sadržajem pretežno organskih zagađivača moguć je primenom cementa kao aditiva. U toku procesa S/S dolazi do očvršćavanja materijala, kroz promene fizičkih osobina cementa. Naročito se preporučuje ukoliko otpad ili materijal sadrži slobodnu vodu, koja ulazi u proces hidratacije, stvarajući sa cementom materijal visoko fizički integrisan monolit. Postupak je pokazao visoku efikasnost u smanjenju mobilnosti opasnih i štetnih materija iz otpada sa sadržajem halogenovanih poluisparljivih i teškoisparljivih policikličnih aromatičnih ugljovodonika (PAH), polihlorovanih bifenila (PCB), pesticida, organskih cijanida i dr.

Nedostatak cementa je neefikasnost primene u slučajevima kada otpad ima visoki sadržaj masti i ulja, kada je onemogućen proces hidratacije cementa. Čestice cementa bivaju obložene uljima ili mastima čime je onemogućen kontakt između ce-

menta i vode. Neke organske komponente utiču na vreme vezivanja cementa, čime ceo postupak solidifikacije može znatno da se produži. Iz navedenih razloga, neophodno je pre izbora aditiva uraditi kompletnu kvalitativnu i kvantitativnu hemijsku analizu otpada, čime se sprečava nastanak neželjenih efekata na samom terenu. Takođe, upotrebom negašenog kreča kao aditiva dolazi do egzotermne reakcije tokom procesa hidratacije, čime se oslobađa znatna količina energije. Ako su u otpadu prisutne lako-isparljive opasne i štetne komponente, iste će tokom procesa S/S biti emitovane u atmosferu. Ako ne postoji druga alternativa negašenom kreču kao aditivu u procesu S/S, neophodno je obezbediti uređaje za sakupljanje i tretman gasova /vazduha[5].

Tretman otpada sa sadržajem teških metala – Primenom kobinovanog postupka stabilizacije i solidifikacije otpada sa sadržajem teških metala, u velikoj meri dolazi do transformacije oblika u kome se teški metali nalaze i prelazak u oblike (najčešće su to teškoraštvoerni hidroksidi) u kojima je smanjena mobilnost jona teških metala.

Solidifikacijom se dodatno smanjuje mobilnost teških metala iz novonastalih teškoraštvoernih oblika (slika 1).

Sl. 1. Proizvod procesa stabilizacije i solidifikacije opasnog otpada sa sadržajem teških metala, primenom Portland cementa kao aditiva [6]

U tabeli 1 prikazane su preporučene metode S/S u zavisnosti od vrste otpada [7].

Tabela 1. Preporučene metode S/S u zavisnosti od vrste otpada

Metoda stabilizacije	Primena
Solidifikacija sa cementom	Muljevi, kontaminirana zemljišta
Solidifikacija sa krečom	Otpad od desulfurizacije otpadnih gasova, drugi neorganski otpad
Solidifikacija sa termopalstičnim materijalima	Radioaktivni otpad
Enkapsulacija	Muljevi, tečnosti, određene materije
Vitrifikacija	Ekstremno opasan otpad, radioaktivni otpad

Model za izbor aditiva u zavisnosti od vrste otpada

U cilju lakšeg izbora aditiva u zavisnosti od vrste otpada sprovedena su istraživanja od strane autora B. K. C. Chan i ostalih. Ispitivani materijali za izradu modela za izbor aditiva bili su sledeći: JR-otpada sa najvećim sadržajem opasnih komponenti nastao kao posledica rudarskih aktivnosti, OMW-fino granulirani otpad sa niskim

sadržajem opasnih komponenti. Ispitivani aditivi su SS-kvarcni pesak, PC-komercijalno dostupni Portland cement, FA-leteći pepeo i L-kreč.

U tabeli 2 prikazani su rezultati ispitivanja stabilizacije opasnog otpada sa različitim sadržajem opasnih komponenti primenom različitih aditiva i sa različitim udelom [8].

Tabela 2. Rezultati ispitivanja stabilizacije opasnog otpada sa različitim sadržajem opasnih komponenti primenom različitih aditiva

Mix	% Osušenog kontaminiranog zemljišta/otpada						Udeo voda/otpada
	PC	FA	SS	OMW	JR	L	
5PC-FA	5	15	80	-	-	-	0.20
5PC-FA-OMW	5	15	70	10	-	-	0.30
5PC-FA-JR	5	15	70	-	10	-	0.25
10PC-FA-JR	10	15	65	-	10	-	0.30
10L-FA-JR	-	15	65	-	10	10	0.43
5PC-FA-L-JR	5	15	65	-	10	5	0.41

Koncentracije teških elemenata As, Cd, Co, Cu, Mn, Mo i Ni u otpadu nakon predtretmana, dobijene sprovođenjem propisanih procedura ispitivanja opasnih i toksičnih karakteristika otpada bili su ispod granice dozvoljenih vrednosti za podzemne vode i zemljište, čak i iz uzoraka otpada koji ima povećani sadržaj opasnih komponenti.

Adsorpcija na hidratizirani gvožđe (III) oksid prisutnog u uzorcima smanjila je

mobilitet jona arsena. Međutim sadržaj barijuma je iznad propisanih granica u svim ispitivanim slučajevima. Takođe, amfoterni Cr, Pb i Zn su preko granica dozvoljenih kada je ispitivani uzorak bio JR.

Rezultati ispitivanja kontaminiranog zemljišta sa manjim sadržajem opasnih komponenti, a nakon sprovedenog postupka predtretmana, dao je zadovoljavajuće rezultate.

U tabeli 3 prikazani su rezultati ispitivanja primene različitih aditiva (kreč, UFS-livnički pesak iz železare Smederevo) za stabilizaciju otpada nastao rudarskim aktiv-

nostima sa područja Bora, Srbija, sa sadržajem teških metala: bakar (0.12%), gvožđe (4.06%), olovo (0.07%) i cink (0.07%) [9].

Tabela 3. Mobilnost jona teških metala nakon stabilizacije u 4 ciklusa primenom različitih aditiva.

Mešavina	Metal	mg/L			
		1	2	3	4
Materijal sa brane 3A	Cu	11.8	11.6	10.8	10.8
	Fe	8.1	4.4	6.5	4.3
	Pb	<1	<1	<1	<1
	Zn	5.2	5.1	6.6	5.9
Materijal sa brane 3A + (100% kreč)	Cu	0.24	0.21	0.27	0.27
	Fe	<0.05	<0.05	<0.05	<0.05
	Pb	<1	<1	<1	<1
	Zn	0.34	<1	<1	<1
Materijal sa brane 3A + (100% UFS)	Cu	12.93	16.14	18.44	16.98
	Fe	7.395	5.882	2.689	2.857
	Pb	<1	<1	<1	<1
	Zn	11.19	13.19	13.79	13.15
Materijal sa brane 3A + (90% UFS + 10% kreč)	Cu	n.d	n.d	n.d	0.077
	Fe	0.336	0.336	0.336	0.336
	Pb	0.714	0.714	0.714	0.714
	Zn	0.128	0.085	0.128	0.255
Materijal sa brane 3A + (75% UFS + 25 kreč)	Cu	n.d	0.077	n.d	n.d
	Fe	0.336	0.336	0.504	0.336
	Pb	n.d	n.d	n.d	n.d
	Zn	0.213	0.043	0.085	0.170

Najbolji rezultati su dobijeni primenom kreča kao aditiva, što se moglo i očekivati, jer se radi o otpadu neorgan-skog porekla sa povećanim sadržajem teških metala.

Faktori koji utiču na efikasnost stabilizacije i solidifikacije

Pravilan izbor reagensa. Stabilizacija otpada nastao kao posledica rudarskih aktivnosti sa velikim sadržajem vodene faze. Postupak koji se preporučuje u slučaju stabilizacije opasnog otpada, naročito neorgan-skog otpada sa sadržajem teških metala, je

neutralizacija krečom iz razloga stvaranja teškorastvornih hidroksida u alkalnim uslovima sredine, što je istraživanje M. Korać i ostali, prikazano u tabeli 3, potvrdilo.

Dodatno, u postupku solidifikacije može nastati po površini zrna, u prisustvu silicijuma i aluminijuma, nepropusna barijera kalcijum-silikatni gel ili kalcijum-aluminatni gel, čime se povećava efikasnost postupka [10].

Kriva rastvorljivosti hidroksida teških metala u zavisnosti od pH vrednosti sredine prikazana je na slici 2, čime se jasno uočava uticaj pH vrednosti na mobilnost teških metala [5].

Sl. 2. Kriva rastvorljivosti hidroksida teških metala u zavisnosti od pH vrednosti [5]

Vreme starenja produkta stabilizacije i solidifikacije – Tretman nastalog produkta nakon procesa solidifikacije i stabilizacije otpadnog materijala može imati značajni efekat na efikasnost postupka. Na slici 3 prikazan je uticaj temperature i uslova

sušenja i vremena starenja na mobilnost cinkovih jona u mulju.

Sa slike se jasno uočava da starenje od 6 meseci pri temperaturi od 25°C, pri atmosferskim uslovima, smanjuje mobilnost jona cinkana na ispod 10 mg/L [5].

Sl. 3. Uticaj temperature i uslova sušenja i vremena starenja na mobilnost cinkovih jona u mulju [5]

Na slici 4 grafički je prikazana zastupljenost pojedinih postupaka stabilizacije i

solidifikacije u procesu predtretmana opasnog otpada pre odlaganja [11].

Sl. 4. Zastupljenost pojedinih postupaka stabilizacije i solidifikacije u procesu predtretmana opasnog otpada pre odlaganja [11]

ZAKLJUČAK

Promenom fizičkog karaktera otpada primenom solidifikacije, sprečava se nastanak velike količine procednih voda na deponiji, sa visokim sadržajem opasnih i štetnih komponenti; čime se postiže dvostruki efekat, štiti se životna sredina, a sa druge strane smanjuje ekonomski efekat procesa zbrinjavanja opasnog otpada, jer nema potrebe za instalacijom i radom sistema za prečišćavanje otpadnih/procednih voda sa deponije.

Izbor postupka stabilizacije i solidifikacije, tj. aditiva jedan je od ključnih elemenata koji najviše utiču na efikasnost primenjenog postupka. Iz tog razloga najbitniji korak u procesu stabilizacije i solidifikacije otpadnog materijala predstavlja

kvalitativna i kvantitativna analiza otpadnog materijala, na osnovu koje se može izvršiti izbor pravog aditiva za proces S/S.

Neophodno je proveriti uticaj starenja i uslova starenja nastalog produkta S/S procesa na mobilnost opasnih i štetnih komponenti iz otpad, čime je moguće povećati efikasnost procesa predtretmana.

Procesi S/S se ne primenjuju na otpadne materijale sa sadržajem poluisparljivih i lakoisparljivih organskih komponenti. Osnovni razlog je što usled procesa S/S može doći do oslobađanja toplotne energije, čime bi se povećao uticaj opasnog otpada na životnu sredinu emisijom opasnih i štetnih komponenti u vazduh.

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