Potential Use of Saline Wastewater for the Agglomeration of Fluidized Fly Ash

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http://doi.org/10.29227/IM-2018-02-34

Abstract

Experiments carried out within the research aimed to determine the influence of saline water on the properties of additivated granulate through interpreting extraction tests. Two types of mixing water of different degrees of mineralization were tested. Raw untreated water was used as a control sample. In assessing the potential use of saline water in the agglomeration of fluidized fly ash, aqueous extracts of fluidized-bed granulate mixed with water were subjected to analyses in accordance with valid legislation and standards. Based on the findings we identified their suitability for subsequent use. The main aim of the experiment was to compare the extraction test results of crushed and uncrushed granulate, which more or less fulfilled prerequisites of the intended testing. According to the obtained results it can be clearly seen that the mixing of salty water is recommended for use in the manufacture adducted granulate regardless of whether it is adducted granulate crushed or uncrushed, moistened raw untreated or salty water.

Keywords: saline water, CFBC fly ash, additivated granulate

Submission date: 11-09-2018 | Review date: 24-10-2018

Introduction

Electricity generation leads to a number of ecological problems, such as the inevitable formation of gas emissions, solid combustion products or saline wastewater. Combined electricity and heat production, in comparison to other production technologies of electricity and heat, has been known for the most efficient use of fuel in the energy sector [1, 2]. However, lower grade brown coal with high ash contents has been increasingly used in the electricity and heat generation, which results in the production of enormous quantities of a secondary energy product, i.e. fly ash. This needs to be either processed to be subsequently used as a secondary raw material, or disposed as waste in a landfill. One of the effective options to utilize fluidized fly ash is to mix it with water to produce a certified product, i.e. additivated granulate. Another option is to keep the fluidized fly ash in the dry state, i.e. dry ash. [3, 4]

Heating plant technologies are often adapted for the processing of the secondary energy product and using agglomeration process they convert it into additivated granulate. In this process saline water is used to moisten the granulate. The resulting agglomerate may be used, for example, as a remediation material in the land reclamation related to coal mining, or in backfilling and infilling during road construction. The remaining dry ash mainly from the cloth filters can be used, for example, as an additive for mortar mixtures and for the production of aerated concrete. This way no waste fluidized fly ash remains because all the secondary energy products have the status of certified products and need to be treated as such. [5, 6]

One of the main problems related to the management of solid residues from combustion are the contents of toxic metals. Brown coal fly ash typically contains toxic elements, such as As, Pb, Zn, Se, Cd, Co, Ni, Cu, V or Cr. These may leach from fly ash and contaminate the soil, surface or ground water. [6, 7, 8]

Since the saline wastewater is highly variable, it is not possible to define the constant qualitative parameters precisely. Some studies focus on the application of saline water as mixing water for the production of concrete, for example. In the experiments the used saline water had a similar composition to sea water. It has been found that using saline water, the produced concrete manifested much higher compression strength than the concrete produced with mixing drinking water. The common practice in the manufacturing of concrete is to apply chloride compounds to accelerate the strength development and improve the mechanical properties. Preliminary studies show that the coal ash has similar properties as cement and during its mixing with saline water it may have beneficial effects on the functional properties of the resulting material. [9, 10]

Recently, a series of experiments have been performed to assess the suitability of saline water for the agglomeration of the fluidized fly ash. This research has been carried out, for example, by Kouba, who performed leaching tests of various granulates having potentially worst possible hypotheses as for the mixing water composition. But in fact will never final salty water dispose for example by concentration of the sample from the chemical thermal water treatment. In his research, Kouba analyzed aqueous extracts using only mature, unground granulate bodies (rollers) which had been 100% subjected to Standard Proctor compaction test. He tested uncrushed bodies of additivated granulate with regard

Tab. 1. The results of analysis of the test batch water [Legend: RUW – raw untreated water, MSW1 – mixing saline water 1, MSW2 – mixing saline water 2]
Tab. 1. Wyniki analizy próbek RUW – woda surowa, MSW1- mieszanina z wodą słoną 1, MSW2 - mieszanina z wodą słoną 2

Parameters	Units	Samples		
		RUW	MSW1	MSW2
pH	-	7.3	8.4	8.9
CODCr	mg/l	28	49.9	35.4
DIS	mg/l	68	810	2.826
Dissolved solids	mg/l	182	-	-
Chlorides	mg/l	27	117	420
Sulfates	mg/l	-	250	530
Conductivity	mS/m	429	550	750

Tab. 2. Extraction tests of the crushed cylinders according to Decree 294/2005 Coll [Legend: DGS crushed granulate with mixing raw untreated water, DG-ZSV1 – crushed granulate with mixing saline water 1, DGZSV2 – crushed granulate with mixing saline water 2, colour marking determines the classification of the measured values into the appropriate leachability class]
Tab. 2. Próby ekstrakcyjne próbek rozdrobnionych zgodnie z Rozporządzeniem 294/2005 Coll [oznaczenia: DGS kruszony granulat w wodzie surowej nieoczyszczonej, DGZSV1 – rozdrobniony granulat w miesznínie solanki z wodą 1, DGZSV2 – rozdrobniony granulat w mieszaninie z solą 2, kolor określa klasyfikację zmierzonych wartości do odpowiedniej klasy wymywalności]

Test specimens of crushed cylinders								
Parameters	Units	Samples			Leachability class			
		C/UGUW	C/UMSW1	C/UMSW2	I	IIa	IIb	III
Chlorides	mg/l	4	23	220	80	1.500	1.500	2.500
Sulfates	mg/l	934	935	1 250	100	3.000	2.000	5.000
As	mg/l	<0.02	0.03	0.04	0.05	2.5	0.2	2.5
Ba	mg/l	0.1	0.1	0.1	2	30	10	30
Cd	mg/l	<0.002	<0.002	<0.002	0.004	0.5	0.1	0.5
Cr total	mg/l	0.06	0.06	0.06	0.05	7	1	7
Cu	mg/l	<0.002	<0.002	<0.002	0.2	10	5	10
Hg	mg/l	<0.001	<0.001	<0.001	0.001	0.2	0.02	0.2
Ni	mg/l	<0.004	<0.004	<0.004	0.04	4	1	4
Pb	mg/l	<0.020	<0.020	<0.020	0.05	5	1	5
Sb	mg/l	<0.004	<0.004	<0.001	0.006	0.5	0.07	0.5
Se	mg/l	<0.03	<0.03	<0.03	0.01	0.7	0.05	0.7
Zn	mg/l	<0.005	0.2	0,3	0,4	20	5	20
Mo	mg/l	0.05	0.05	0.04	0.05	3	1	3
Dissolved solids	mg/l	1.534	1.534	2.225	400	8.000	6.000	10.000
pH	-	11	11	11	-	≥6	≥6	-

to the purpose of use in practice, where always forms a compact body. Since the samples used were not crushed to an optimum grain size up to 10 mm, the results deviated from the determination methodology according to the valid norms used for single stage batch test at a liquid to solid ratio of 10 L/kg for materials with particle size below 10 mm. This prompted us to implement an experiment in which we carried out leaching tests of additivated granulates both in the crushed and uncrushed states (using mixing saline water). The results of the crushed / uncrushed granulate needed to be compared with the valid Decree 294/2005 Coll., on the conditions of depositing waste in landfills and its use on the ground surface, and amendments to Decree 383/2001 Coll., on details of waste management, and according to the valid product certificate 204/C5/2014/040-045539. The experiment also assessed the direct effects of saline water on the additivated granulate subject to several observed parameters, such as pH and chloride content. [11, 12]

Our aim was to assess the potential use of saline water, as a waste product from related technological processes of electricity and heat generation, to agglomerate fluidized fly ash. This wastewater should thus have both the mixing and moisturizing function. In case of positive results, this application option may have a big impact on higher efficiency of the existing technologies both in handling fluidized fly ash and saline water, taking into account their toxicity and related environmental risks.

Materials and Methods

A required amount of fly ash was sampled in the dry state for the intended standard procedure testing. The optimal moisture content (40%) for all batches was determined for the tested samples according to the local

Tab. 3. Extraction tests of the uncrushed cylinders according to Decree 294/2005 Coll [Legend: NGS crushed granulate with mixing raw untreated water, NGZSV1 – crushed granulate with mixing saline water 1, NGZSV2 – crushed granulate with mixing saline water 2, color marking determines the classification of measured values into the appropriate leachability class]

Tab. 2. Próby ekstrakcyjne próbek nierozdrobnionych zgodnie z normą 294/2005 Coll [oznaczenia: DGS kruszony granulat w wodzie surowej nieoczyszczonej, DGZSV1 – rozdrobniony granulat w mieszninie solanki z wodą 1, DGZSV2 – rozdrobniony granulat w mieszaninie z solą 2, kolor określa klasyfikację zmierzonych wartości do odpowiedniej klasy wymywalności]

Test specimens of uncrushed cylinders								
Parameters	Units	Samples			Leachability class			
		C/UGUW	C/UMSW1	C/UMSW2	I	IIa	IIb	III
Chlorides	mg/l	4	6	77	80	1.500	1.500	2.500
Sulfates	mg/l	626	442	608	100	3.000	2.000	5.000
As	mg/l	<0.02	<0.02	0.03	0.05	2.5	0.2	2.5
Ba	mg/l	0.1	0.1	0.1	2	30	10	30
Cd	mg/l	<0.002	<0.002	<0.002	0.004	0.5	0.1	0.5
Cr total	mg/l	0.07	0.06	0.04	0.05	7	1	7
Cu	mg/l	<0.002	<0.002	<0.002	0.2	10	5	10
Hg	mg/l	<0.001	<0.001	<0.001	0.001	0.2	0.02	0.2
Ni	mg/l	<0.003	<0.003	<0.003	0.04	4	1	4
Pb	mg/l	<0.020	<0.020	<0.020	0.05	5	1	5
Sb	mg/l	<0.004	<0.004	<0.004	0.006	0.5	0.07	0.5
Se	mg/l	<0.03	<0.03	<0.03	0.01	0.7	0.05	0.7
Zn	mg/l	<0.001	<0.001	0.02	0,4	20	5	20
Mo	mg/l	0.03	0.03	0.04	0.05	3	1	3
Dissolved solids	mg/l	789	987	1,197	400	8.000	6.000	10.000
pH	-	11	10	10	-	≥6	≥6	-

heating plant and production processes, and according to the valid additivated granulate certificate.

The test specimens were prepared having compacted the granulate into an atypical mold with a piston for pressing. The sample was compacted using a vise at the maximum torque, which resulted into a much more efficient compaction than using the Standard Proctor test. The granulate test specimens in the form of cylinders (dimensions 40 × 80 mm) were stored in an air-conditioned box (producer Snaige) for twenty-eight-day maturing. The granulate specimens were prepared with different mixing waters and for the control sample we used raw untreated water. The samples were labelled according to the used mixing water and grain size as follows:

- C/UGUW (crushed/uncrushed granulate with raw untreated water),
- C/UMSW1 (crushed/uncrushed granulate with less mineralized saline water 1),
- C/UMSW2 (crushed/uncrushed granulate with more mineralized saline water 2).

In order to compare the leachability of the crushed and uncrushed granulate, two pieces of test specimens were produced from each sample. After twenty-eight-day maturation, one cylinder was left as whole and the second was crushed fractions below 10 mm according to the relevant standards for single-stage batch tests at a liquid to solid ratio of 10 L/kg for materials with particle size below 10 mm (with/ without particle size reduction). Such prepared samples were subjected to leaching tests.

The pH value of the mixing water and leachate was determined with a pH meter (pH inoLab 7110), chemical oxygen demand was determined using the chroman method (CODCr), the content of dissolved inorganic salts (DIS) was determined using the gravimetric method for filtration through glass fibre filters, chlorides were determined using the argentometric determination with chromate indicator (Mohr's method), and the conductivity using a conductometer (WTW cond 330i). When establishing the leachability of the crushed and uncrushed granulates we were analysed selected elements (Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Ni, Mo, Pb, Sb, Se, Sn, V and Zn), namely via the optical emission spectrometry with inductively coupled plasma (ICP - OES) using the Spectro Genesis spectrophotometer.

The results obtained from the leaching tests were evaluated as wastes according to the Appendix 10 of Decree 294/2005 Coll., stipulating the conditions for depositing waste in landfills and their use on the ground surface, and amendments to Decree 383/2001 Coll., on details of waste handling as a product according to the valid certificate 204/C5/2014/040 045539.

Results and Discussion

During testing we tried to simulate the behaviour of the additivated granulate as a certified product for infills and backfills in the road construction, when the additivated granulate is layered and compacted by heavy machinery under extreme pressure. This leads to more effective solidification than in case of loose granulate deposited in a landfill.

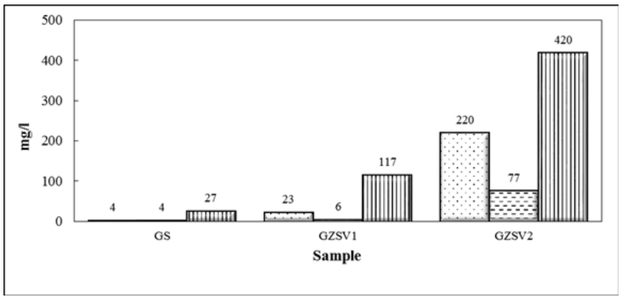

Fig. 1. The leachability of crushed and uncrushed specimens according to Decree 294/2005 Coll for chlorides [Legend: GUW - granulate with raw untreated water, GMSW1 – granulate with mixing saline water 1, GMSW2 – granulate with mixing saline water 2]
Rys. 1. Próby wymywania próbek rozdrobnionych i nierozdrobnionych zgodnie z normą 294/2005 Coll [oznaczenia: GUW- granulat w wodzie surowej, GMSW1 – granulat w wodzie z solanką 1, GMSW2 – granulat w wodzie z solanką 2]

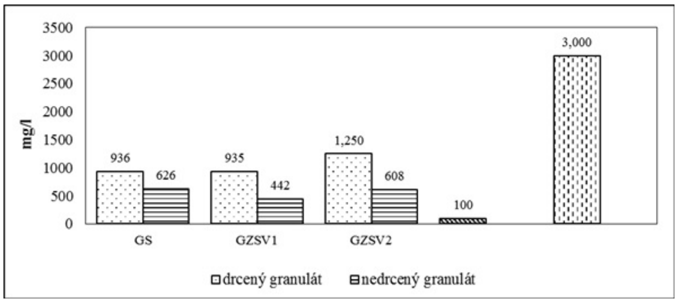

Fig. 2. The leachability of crushed and uncrushed specimens according to Decree 294/2005 Coll. for sulphates [Legend: GUW – granulate with raw water, GMSW1 – granulate with mixing saline water 1, GMSW2 – granulate with mixing saline water 2]
Rys. 2. Wymywalność siarczanów rozdrobnionych i nierozdrobnionych próbek [oznaczenia: GUW- granulat w wodzie surowej, GMSW1 – granulat w wodzie z solanką 1, GMSW2 – granulat w wodzie z solanką 2]

We also analysed three types of mixing water for the suitability of saline water applied in the agglomeration of fluid fly ash. Table 1 below shows the measured values of all the observed parameters of the tested samples: raw untreated water (RUW), the mixing saline water 1 (MSW1) and mixing saline water 2 (MSW2). The analyses of the different water samples imply that sample MSW2 is more mineralized, which should be reflected in an increased chloride content in the extracts from this sample.

The following tests aimed to verify the hypothesis that the compacted additivated granulate releases much lower amounts of undesirable substances than the crushed or loosely placed additivated granules in a landfill. To realize this experiment we needed to adjust the dimensions of the cylinders, or reduce their mass to 100 g, to be able to compare the leachability of the two groups of samples (crushed/uncrushed). Table 2 shows the results of the leachability tests of the crushed cylinders, evaluated according to Decree 294/2005 Coll. The extraction test results of the crushed granulate cylinders are satisfactory as they meet the leachability class IIa limit. It can be stated that the results obtained in the case of saline water, which was less mineralized, even meet the limit for leachability class I for chloride content. The frequently discussed toxic metal contents in the leachate, except for total chromium which slightly exceeds the leachability class I limit (0.05 mg/l), comply with limits for leachability class I.

On the grounds of the leachability results of the uncrushed granulate specimens we can state that in comparison with the test specimens of the crushed granulate cylinders, there was a significant reduction in both the content of chlorides, sulfates, and the total dissolved solids (see Table 3). In case of the chloride content in samples C/UMSW2 (uncrushed granulate with mixing saline water 2) the leachability limit shifted from leachability class IIa to leachability class I. The limit concentrations for leachability class I in dissolved solids were not met in either the unground or ground granulates. As a result, all the tested granulate samples were classified into the leachability class IIa due to their high content of dissolved solids, subject to Decree 294/2005 Coll. According to the decree, the differently prepared extracts of granulates, except for sample NGZSV2 (uncrushed granules with saline water 2), do not meet the leachability class I as they exceed the limit concentration (0.05 mg/ l) for total chromium.

Figure 1 gives a graphic representation of the leachability results of crushed and uncrushed bodies for chlorides. The graph also shows the content of chlorides in the different kinds of mixing water, so to identify their direct impact on the additivated granulate. The obtained results indicate that the non-compacted and compacted fly ash matrix of all the tested samples are capable of an effective demobilisation of chloride leach.

Figure 2 graphically evaluates the sulphate content in the leachates of all three groups of crushed and un-

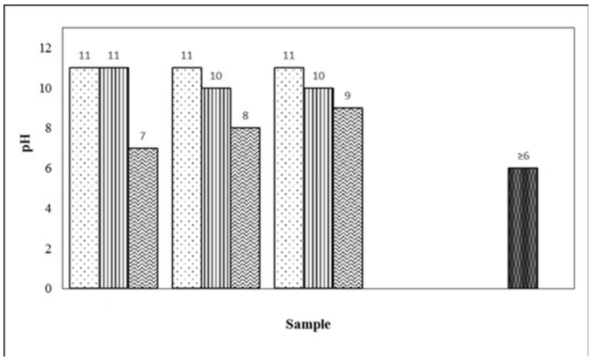

Fig. 3. The leachability of ground and unground specimens according to Decree 294/2005 Coll. for pH [Legend: GUW – granulate with raw untreated water, GMSW1 – granulate with mixing saline water 1, GMSW2 – granulate to the mixing saline water 2]
Rys. 3. Wymywalność próbek zmielonych i niemielonych [oznaczenia: GUW- granulat w wodzie surowej, GMSW1 – granulat w wodzie z solanką 1, GMSW2 – granulat w wodzie z solanką 2]

crushed samples for the different types of used mixing water. There has also been a noticeable reduction in sulphate leachability when using uncrushed granulate, even if the values still belong to leachability class IIa. Based on this finding, in case the additivated granulate is not used as a certified product (regardless of having been crushed or not, moistened with raw untreated or saline water), the granulate would have to be disposed in the landfill for other waste S-001 (landfill intended for storing waste with a low content of biodegradable waste) in line with Decree 294/2005 Coll.

The findings more or less fulfilled our expectations based on the hypothesis of uncrushed granulate leachates due to significant reductions in the surface area of the granulate, and thus much better results of leachability than in crushed granulate. In assessing the suitability of using saline mixing water for the agglomeration of fluid fly ash, it is apparent that in case of the sample GUW (granulate with mixing raw untreated water) we achieved even worse results than with sample D/NGMSW1 (crushed/uncrushed granulate with mixing saline water 1) and NGMSW2 (uncrushed granulate with mixing saline water 2). This implies that that the saline water in some cases may even have a positive influence on the retention of sulphates in the compacted fly ash matrix.

Based on the relatively high pH values in all granulate samples (see Fig. 3), all the granulate specimens may be classified into leachability class IIa according to Decree 294/2005 Coll. In order to assess the impact of mixing water onto the additivated granulate, the graph also gives the measured pH values of the mixing water. It is clear that the pH of the fly ash (addiotivated granulate matrix) is in the alkaline range. Based on this finding, we may assume that neutral pH of the mixing raw untreated water and also the slightly alkaline pH of the mixing saline water, may slightly compensate the resulting pH of the additivated granulate.

When assessing the extracts according to the product certificate we only compare the limits of toxic metals and some of them are taken from leachability class I as in Decree 294/2005 Coll. Other limit concentrations for the toxic metals are modified according to the relevant technical standards or technical manuals. However, even in this case, the limits set in the certificate were not exceeded (see Table 4), although the rounded resulting concentration values for total chromium and vanadium equalled to the set allowable concentration limit according to the product certificate.

Table 5 shows the results of leachates for the monitored elements, heavy metals in samples of UGUW (uncrushed granulate with raw untreated water), UGMSW1 (uncrushed granulate with mixing saline water 1) and UGMSW2 (uncrushed granulate with mixing salty water 2) according to product certification limits.

Vanadium appears as one of the most problematic elements tested within the granulate leaching tests and according to the limits specified in the leachability certificate. Its content has been detected at all compacted solids to equal the limit level (0.2 mg/l). Still, all the samples comply with the concentration limits in the certificate. Another problematic element is the total chromium. It's content in the samples amounts to the certificate specified limit concentration of 0.1 mg/l, except for the sample UGMSW2 which showed a concentration of 0.04 mg/l. Other monitored toxic metals in the crushed and uncrushed samples sufficiently comply with the limit concentrations declared in the valid certificate.

The carried experiment confirmed our expectations because the uncrushed granulate really showed much better results than the leaching tests using the granulate crushed to a particular grain size. Based on the results, it is apparent that the leachability of toxic metals in the granulate using the mixing saline water did not have any significant negative effects.

Conclusion

According to the obtained results it can be clearly seen that the mixing of salty water is recommended for use in the manufacture adducted granulate regardless of

Tab. 4. Leach tests of crushed granulate according to the applicable limits of the certified additivated granulate product used for backfills and infills in road construction [Legend: CGUW crushed granulate with mixing raw untreated water, CGMSW1 – crushed granulate with mixing saline water 1, CGMSW2 – crushed granulate with mixing saline water 2]

Tab. 4. Testy wymywalności z zastosowaniem limitów dla certyfikowanych granulatów do zastosowania w budownictwie drogowym [oznaczenia: GUW- granulat w wodzie surowej, GMSW1 – granulat w wodzie z solanką 1, GMSW2 – granulat w wodzie z solanką 2]

Parameters	Units	Certificate limits	Samples		
			CGUW	CGMSW1	CGMSW2
Ag	mg/l	**0.1**	<0.010	<0.010	<0.010
As	mg/l	**0.1**	<0.02	0.03	0.04
Ba	mg/l	**0.291**	0.077	0.100	0.110
Be	mg/l	**0.005**	<0.003	<0.003	<0.003
Cd	mg/l	**0.005**	<0.002	<0.002	<0.002
Co	mg/l	**0.1**	<0.003	<0.003	<0.003
Cr total	mg/l	**0.1**	0.1	0.1	0.1
Cu	mg/l	**1.0**	<0.002	<0.002	<0.002
Hg	mg/l	**0.005**	<0.001	<0.001	<0.001
Ni	mg/l	**0.1**	<0.004	<0.004	<0.004
Pb	mg/l	**0.1**	<0.020	<0.020	<0.020
Se	mg/l	**0.05**	<0.03	<0.03	<0.03
V	mg/l	**0.2**	0.2	0.2	0.2
Zn	mg/l	**3.0**	<0.002	<0.002	<0.002
Sn	mg/l	**1.0**	0.1	0.1	0.1

Tab. 5. Leach tests of uncrushed granules according to the applicable limits of the certified additivated granulate product used for backfills and infills in road construction [Legend: UGUW – uncrushed granulate with mixing raw untreated water, UGMSW1 – uncrushed granulate with mixing saline water 1, UGMSW2 – uncrushed granulate with mixing saline water 2]

Tab. 5. Testy wymywalności dla granulatu niekruszonego z zastosowaniem limitów dla certyfikowanego kruszywa do budiownictwa drogowego – oznaczenia jak w tabeli 4

Parameters	Units	Certificate limits	Samples		
			UGUW	UGMSW1	UGMSW2
Ag	mg/l	**0.1**	<0.010	<0.010	<0.010
As	mg/l	**0.1**	<0.02	<0.02	0.03
Ba	mg/l	**0.291**	0.120	0.070	0.075
Be	mg/l	**1.0**	<0.003	<0.003	<0.003
Cd	mg/l	**0.005**	<0.002	<0.002	<0.002
Co	mg/l	**0.1**	<0.003	<0.003	<0.003
Cr	mg/l	**0.1**	0.1	0.1	0.04
Cu	mg/l	**1.0**	<0.002	<0.002	<0.002
Hg	mg/l	**0.005**	<0.001	<0.001	<0.001
Ni	mg/l	**0.1**	<0.003	<0.003	<0.003
Pb	mg/l	**0.1**	<0.020	<0.020	<0.020
Se	mg/l	**0.05**	<0.03	<0.03	<0.03
V	mg/l	**0.2**	0.2	0.2	0.2
Zn	mg/l	**3.0**	<0.002	<0.002	<0.002
Sn	mg/l	**1.0**	0.04	0.1	0.1

whether it is adducted granulate crushed or uncrushed, moistened raw untreated or salty water. Based on this knowledge it is not necessary to change the existing technological process of moistening certified product adducted granulate because the certificate's product set optimum humidity range is fully compliant. Salty water can be used without problems for reprocessing fluid fly ash using a technological process of agglomeration, which involves an advantage for the sustainability of continued development of similar technologies. Unmistakable advantages of the use of saline water is to minimize the consumption of surface service water, as well as cost savings on waste water disposal. From an economic perspective, to draw saline water represents for operators significant cost savings that would have to incur for the purchase of raw untreated water to run agglomeration.

It should also be noted that according to the findings, regardless of whether it is adducted granulate crushed or uncrushed, moistened raw untreated or salty water should be granulate in case of non-use of such certified products are always stored in the landfill for other waste S-001. With this finding relate mainly to considerable fees for permanent storage granules to landfills.

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Możliwość wykorzystania zasolonych wód odpadowych do aglomeracji popiołów lotnych

Eksperymenty przeprowadzone w ramach badań miały na celu określenie wpływu zasolenia wody na właściwości granulatu poprzez interpretację testów ekstrakcji. Zbadano dwa typy wody dodawanej do aglomeracji o różnym stopniu mineralizacji. Jako próbkę kontrolną użyto surową nieoczyszczoną wodę. Przy ocenie potencjalnego wykorzystania wody słonej w procesie aglomeracji lotnego popiołu fluidalnego, wodne ekstrakty z granulatu z popiołu fluidalnego zmieszanego z wodą zostały poddane analizom zgodnie z obowiązującymi przepisami i normami. Na podstawie ustaleń określono przydatność aglomeratów do późniejszego użycia. Głównym celem eksperymentu było porównanie wyników próby ekstrakcyjnej rozdrobnionego i nierozdrobnionego granulatu, które w mniejszym lub większym stopniu spełniły warunki zamierzonego badania. Zgodnie z uzyskanymi wynikami można wyraźnie zauważyć, że dodatek słonej wody jest zalecany do stosowania w wytwarzanym granulacie, niezależnie od tego, czy jest to granulat rozdrobniony czy nierozdrobniony, zwilżony, surową, nie poddaną obróbce lub słoną wodę.

Słowa kluczowe: wody zasolone, popioły lotne, dodatki do aglomeracji