

# Fly ash for stabilization of historic mine waste deposits

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## Abstract

Due to ferric iron driven pyrite oxidation, oxygen exclusion alone is not a sufficient method to decrease weathering rates of historic mine waste. By adding an alkaline material, the chemical environment is changed within the deposit: pH is increased and mobilization of common ARD-related trace elements is decreased. Injection and mixing can be performed using alkaline residues such as fly ash, lime mud and green liquor dreg.

Chemical parameters have been studied for five years. The neutralizing capacity of the alkaline material was a key parameter, determining both the neutralizing effect and the longevity. An important observation was lowered water flow in fly ash amended barrels, due to formation of hydrous Ca-Si-Al minerals (hard pan).

Expected results in larger experiments are decreased flow rates, increased pH and accordingly lowered trace element concentrations in the leachates.

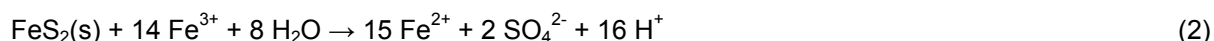
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## INTRODUCTION

During the last years there has been an increased interest for the use of alkaline residues in mine waste remediation. These alkaline residues include for instance lime mud, green liquor dreg and fly ash, suitable as neutralizers and in sealing layers for mine waste.

Acid rock drainage (ARD) typically contains elevated concentrations of dissolved and particulate iron and dissolved sulphate, produced by the oxidation of pyrite, which is the main sulphide mineral in most tailings and waste rock [1, 2]. The primary oxidants of sulphides in tailings and waste rock are usually oxygen and ferric iron. Because of the slow oxygen diffusion rates in water, high concentrations of oxygen must be present in the gas phase to obtain significant oxidation rates. This indicates that significant pyrite oxidation rates can only be achieved in regions of the pile or that are not water saturated [3].

Oxidation of pyrite with oxygen as the oxidant (reaction 1) is limited by the availability of dissolved oxygen. Hence, reaction 1 is the most common reaction for pyrite oxidation in O<sub>2</sub> saturated conditions. As reaction 1 proceeds and generates ferrous iron, the ferrous iron is further oxidized according to reaction 3. Oxidation of pyrite by ferric iron (reaction 2) is rapid and anaerobic. However, the rate-limiting step for this reaction is the oxidation of ferrous iron to ferric iron (reaction 3).



The rate of pyrite oxidation not only depends on oxygen supply, but also on pH, available surface area, morphology of the pyrite, the presence of bacteria and hydrological factors [4, 5]. The optimum pH for maximum pyrite oxidation rate is 2-3 [2].

Oxidation of pyrite by solid ferric hydroxides (reaction 4) (low solubility of ferric hydroxides at neutral and alkaline pH however indicates that the reaction is less important at circum neutral pH (e.g. [6]). Doye and Duchesne [7] showed that the rate of pyrite oxidation declined when a highly alkaline materials was added.



Conventional remediation techniques for mine waste are covering using either dry covers or water covers. However, content of ferric iron in historical oxidized acid mine waste complicates matters. To avoid problems during covering when historical mine waste becomes anoxic (reductive dissolution of secondary iron oxyhydroxides and iron(III) mediated weathering of pyrite) the waste can instead be mixed with an alkaline material to obtain neutralization and increased immobilization of the trace elements [8]. Figure 1 shows the pH-dependent sorption of some common ARD-related trace elements (Cu, Zn, Cd and Pb) onto the surface of a hydrous ferric oxide and a hydrous aluminum oxide [9]. This is due to the increasing negative surface charge of the oxide surface with increasing pH, resulting in strong cation adsorption at high pH. Below the edge of the curve, the ion is not adsorbed or weakly adsorbed and above the edge the ion is strongly adsorbed. At very high pH (above 12) desorption of lead occurs (figure 1, left) due to formation of soluble anionic Pb-complexes.

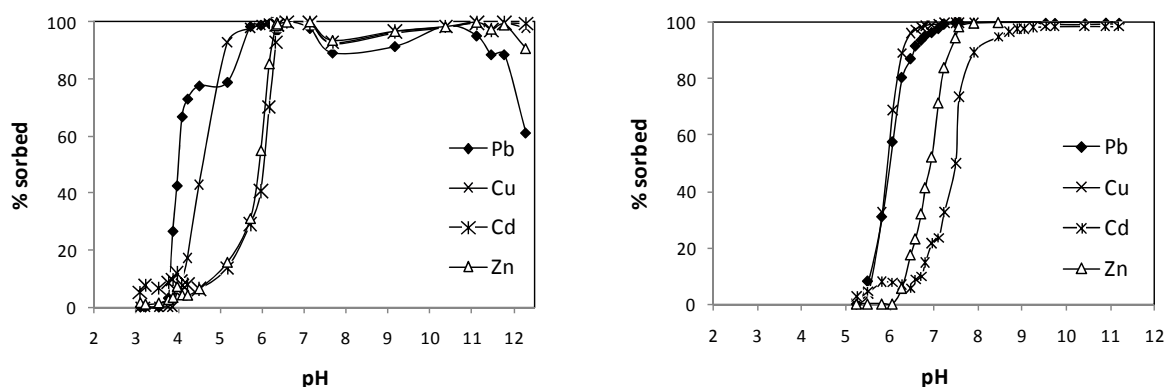


Figure 1: Sorption of Pb, Cu, Cd and Zn onto the surface of a hydrous ferric oxide (left) and a hydrous aluminum oxide (right) as a function of pH [9].

It is possible to make an impermeable layer if the alkaline additive reacts with the waste and form hardpans [10]. Due to the presence of quicklime (CaO) in alkaline materials pozzolanic reactions and hardpan formation are possible. A hardpan is an impermeable barrier, resulting from the formation of calcium-silicate-gel (CSH) and calcium-aluminate-gel (CAH) [11, 12, 13]. As a hardpan makes infiltration of oxygen and water difficult, fly ash or quicklime is sometimes incorporated in sealing layers for waste rock and tailings [14, 15]. A hardpan can however also consist of accumulation of secondary precipitates (goethite, gypsum, jarosite) near the surface of an impoundment/ pile [16].

Mixing can be made using heavy machinery. One drawback, however, is that the visual appearance of the deposit can be changed. The practical mixing depth may also be insufficient in massive deposits. By injecting the material as a slurry the historical values can be preserved to a greater extent since the visual appearance is not changed.

Injection/stabilization have been used in a historic mining district in the western US, where approximately 2-3.5 million tons of tailings, initially dumped in adjacent creeks, have been *in situ* limed with calcite and  $\text{Ca}(\text{OH})_2$  or CaO. The alkaline materials were tilled into the waste and it was found that after 10 years pH had increased with two pH units [17].

The main objective of this study was to look at the suitability of fly ash for slurry injection in historic waste rock deposits, containing highly oxidized material. Both chemical and physical properties of the fly ashes were considered. pH is a crucial parameter for trace element mobility and this was studied with stabilization experiments of mixtures of fly ash and historic mine waste from the Ljusnarsberg mine field, Kopparberg, mid Sweden. The second stage of the study involved initial tests with slurry injection of different types of fly ashes.

## MATERIALS AND METHODS

### Ljusnarsberg mine field

Ljusnarsberg historic mine site is situated in the centre of the town of Kopparberg in the Bergslagen region. The mine field was discovered in 1624 and the latest mining period ceased in 1975. Approximately 65 large or small pitheads have been found within the central parts of the field. It is estimated that a total area of 500×400 m<sup>2</sup> is affected by mining, ore and waste rock dumps.

The mine site is abandoned since 1975. Several waste rock piles remain in the area. Remaining waste rock is heavily oxidized and covered with secondary precipitates [18].

### Study 1: Mixing and layering

The first study focused on determining whether there was a difference or not in how the alkaline source was applied: in distinct layers or thoroughly mixed. Mixing ensures a close and even contact between the acid producing mine waste and the alkaline material, but fly ash, due to its content of free lime, can form hard pans through pozzolanic reactions [19, 20]. Hard pan formations decrease liquid flow and increase the contact time between liquid and alkaline material. Therefore, mixing in distinct layers could be beneficial for fly ash amended systems.

Two types of experiments were performed: layered and mixed (figure 2). Water was added at the top of the containers to simulate precipitation and samples were collected at the outlet (according to figure 2). Samples were occasionally also collected through the suction cups/sampling lysimeters. The layered systems were larger than the mixed, 0.8 m<sup>3</sup> and 30 L, respectively. Also, in the larger systems three different mine waste: fly ash ratios were tested (10, 25 and 50 % fly ash, by volume), whereas in the mixed system only 10 % (by volume) was tested.

The mine waste used in the experiments was a highly oxidized fraction (0-13 mm) of waste rock from the Ljusnarsberg mine field. Secondary aggregates were crushed and sieved prior to use. The fly ashes used in these experiments came from pulp and paper industry (FAF, Korsnäs Frövi, Sweden) and from energy production and district heating (FAE, E.ON, Örebro, Sweden).

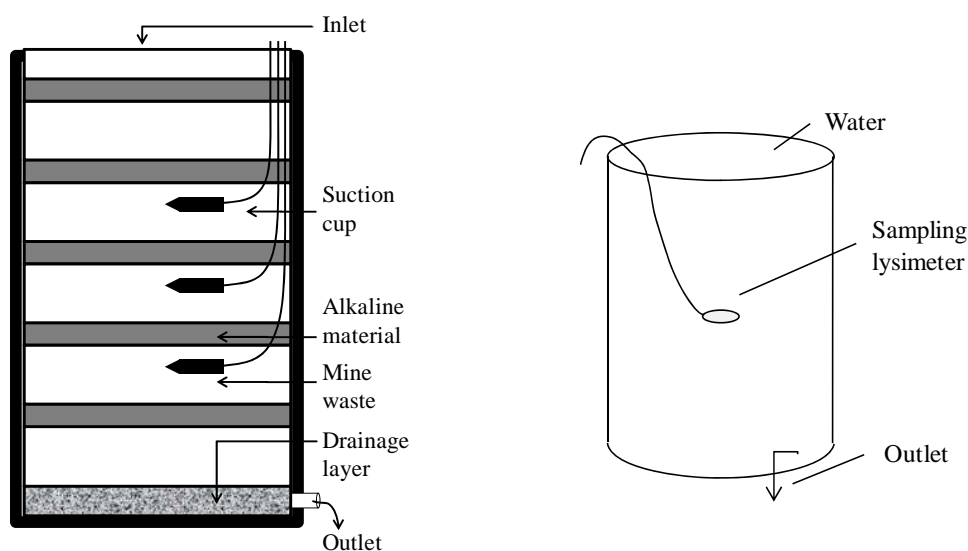


Figure 2: Principal outline of the stabilization systems. Layered systems (left): Mine waste and fly ash (10, 25 and 50 % by volume) in layers in 0.8 m<sup>3</sup> plastic barrels. White layers illustrate the mine waste and the grey layers the alkaline materials. Mixed systems (right): Mixtures of mine waste and fly ash (10 %, by volume) in 30 L plastic barrels.

## Study 2: Injection study, physical and chemical parameters of ten fly ashes

A number of ten fly ashes were collected in order to do a more detailed study on which type of fly ashes that would be the most suitable for injection into weathered waste rock piles. The fly ashes used in the study are shown in table 1.

Table 1: The ten fly ashes used in the study. All ashes came from different Swedish producers. The D/W column states if the ash had been moistened (W: wet) or not (D: dry) before the injection study. Available lime index (CaO, %) was measured according to ASTM C25.

Abbr.	Producer	Facility	Boiler	Fuel	Filter	Additive	D/W	CaO (% dw)
VäP5	Mälarenergi	Västerås	CFB	-	-	-	D	3
VäACV	Mälarenergi	Västerås	CFB	-	-	-	D	4.3
EonW	E.on	Örebro	CFB	Bio	Electro	Limestone, NH <sub>3</sub>	W	4.6
EonD	E.on	Örebro	CFB	Bio	Electro	Limestone, NH <sub>3</sub>	D	7.1
StE	Stora Enso	Fors	CFB	Bio, PC <sup>3</sup>	Electro	NH <sub>3</sub> (SNCR)	D	8.2
KorW	Korsnäs	Frövi	BFB	W, F, S <sup>1</sup>	Electro	CO(NH <sub>2</sub> ) <sub>2</sub> (SNCR)	W	2.2
KorD	Korsnäs	Frövi	BFB	W, F, S <sup>1</sup>	Electro	CO(NH <sub>2</sub> ) <sub>2</sub> (SNCR)	D	6.4
UppG	Vattenfall	Uppsala	Grate	Mu, In <sup>2</sup>	El+B.F. <sup>4</sup>	Ca(OH) <sub>2</sub>	W	2.4
UppB	Vattenfall	Uppsala	Grate	Mu, In <sup>2</sup>	El+B.F. <sup>4</sup>	Ca(OH) <sub>2</sub>	W	<2
Kpbg	Fortum	Kopparberg	Grate	Bio, PC <sup>3</sup>	Cyclone	None	W	4.6

<sup>1</sup>W, F, S: Wood, fiber- and biosludge

<sup>2</sup>Mu, In: Municipal (60 %) and industrial waste

<sup>3</sup>Bio, PC: Bio and pulp chips

<sup>4</sup>El+B.F.: Electro and bag filter

The mine waste used for the injection study was larger pieces (50-200 mm) of the weathered Ljusnarsberg material. Ten 30 L containers were filled with waste rock, together with a pipe (Ø5 cm) installed in the middle of each container (which was to be used as an injection pipe). The weight of the containers filled with waste rock was approximately 50 kg.

For the injection, a set of 5 criteria for injection studies stated by Wikman et al. [21] concerning the properties of the alkaline material was followed: (i) It should be relatively stable in a water suspension, (ii) It must stay in the deposit after injection, (iii) It should be able to fill out the voids in the deposit, (iv) It may preferably have a sealing effect, i.e. allow for pozzolanic reactions and hard pan formation and (v) It should not have a particle size exceeding 1 mm.

Before starting the injection, all the moistened ashes (table 1) were sieved through a 1 mm sieve. Injection of the ashes was made by pouring an ash-slurry (a mixture of fly ash and water) through the pipe, which was successively pulled upwards. The fly ash to water ratio (in order to get suitable slurry properties) was determined using a standardized test (SS-EN 445 2007) where slurries of the materials were poured through a funnel with a diameter of 80 mm. A total of 5 kg fly ash was injected into each container.

The chemical interaction between the potentially suitable fly ashes and acid-producing waste rock was studied by mixing mine waste and the fly ashes shown in table 1 in batches. Experiments were set up in 50 ml Sarstedt tubes. A total of 5 grams of a mixture of mine waste (crushed, homogenized) and the fly ashes in different proportions (0, 5, 10 and 100 % mine waste, by weight) was added to each tube, as well as 50 ml deionized water (18.2 MΩ), giving a liquid/solid ratio (L/S) of 10. The tubes were sealed and agitated (end-over-end shaker). Withdrawal of water samples was made after 24 hrs and thereafter every other day (25 ml sample followed by addition of 25 ml of new 18.2 MΩ water to the tube).

## RESULTS AND DISCUSSION

### Study 1: Mixing and layering

Comparison between mixed and layered experiments is given in table 2. Carbonate materials (lime mud and green liquor dreg) had highest pH and alkalinity in the mixed experiments, and as well highest alkalinity in the layered experiments. Nevertheless, pH in layered experiments was highest for the two fly ashes; actually, the worst performing system in mixed experiments (FAE10) was the best performer in the layered experiments.

Table 2: Comparison between mixed and layered experiments. The comparison is only made for the same per cent of alkaline addition (10 %).

Alkaline amendment	pH mixed	pH layered	Alkalinity (meq/L) mixed	Alkalinity (meq/L) Layered
Fly ash, FAF10	6.3	6.1	5.5	3.5
Fly ash, FAE10	5.1	6.4	0.0	1.8
Lime mud, LM10	6.6	5.7	13.5	5.8
Green liquor dreg, GLD10	6.6	6.0	12.4	7.9
Mine waste	2.7	2.6	0.0	0.0

Measuring of flow rates in the different experiments showed no differences between carbonate or hydroxide materials in the mixed experiments. For the layered experiments however, the flow rate was at least two times slower in fly ash systems than in carbonate systems, thus indicating hard pan formation in layered fly ash amended systems. The higher pH for the fly ash systems in the layered experiments is therefore suggested due to longer contact time between the alkaline material and the acid leachate.

Trace elements immobilization is strongly connected to pH (figure 1) and it becomes apparent that e.g. fly ash (FAE10) performs much better in the layered experiment than in the mixed, probably due to the formation of hard pans. On the contrary, carbonate materials (GLD10 and LM10) perform better when they are mixed than when they are layered.

### Study 2: Injection study, physical and chemical parameters of ten fly ashes

In order to get a suitable slurry for injection according to the funnel test (SS-EN 445 2007), between 1.5 and 2 L of water was added to 5 kg of fly ash. The results from the injections are shown in table 3, focusing on criteria (i) and (iv) [21]. Criteria (ii) and (iii) have not yet been evaluated; they will be evaluated at the end of the experiment. The last criteria (v) was valued even before the start of the slurry preparations, and it was found that all the ashes that had been moistened (W in table 1) contained agglomerates larger than 1 mm and these were consequently sieved before starting the injections.

Table 3: Results from the injections. Columns 2 and 3 concern criteria (i) and columns 4 and 5 concern criteria (iv). Text in red color means that there were difficulties with the injection.

Ash	Stable suspension	Too much separation	Hardening	Too rapid hardening	Comments
VäP5	Yes	No	No	No	Easy to form slurry and to inject
VäACV	Yes	No	No	No	Easy to form slurry and to inject
EonW	No	Yes	No	No	Unable to form injectable suspension
EonD	Yes	No	Yes	No	Easy to form slurry and to inject
StE	Yes	No	Yes	Yes	Only 2.5 kg injected due to hardening
KorW	No	Yes	No	No	Unable to form injectable suspension
KorD	No	No	No	No	Some separation, but easy to inject
UppG	No	No	No	No	Some separation, but easy to inject
UppB	No	No	No	No	Some separation, but easy to inject
Kpbg	No	Yes	No	No	Only 2.5 kg injected due to separation

Three of the ashes showed difficulties with keeping an injectable suspension, all of these had been moistened before the injection (EonW, KorW and Kpbg). For Kpbg it was only possible to inject 2.5 kg, and for EonW and KorW no slurry at all was achieved and it was therefore not even possible to do the funnel test. The other two pre-moistened ashes: UppG and UppB showed some difficulties with keeping the fly ash slurries in suspension, but as long as the slurry was gently stirred there was no problem with the injection. This was also the case for KorD (table 3).

Two of the ashes had a free lime content high enough for hardening, these were StE and EonD (see table 1 for free lime content). Hardening of the StE-ash was however a little bit too fast; it was only possible to inject 2.5 kg before the slurry had filled up and hardened in the injection pipe. Injection of EonD was easily performed with a stable suspension and some hardening, but not as rapid as for the StE-ash.

The two ashes from Västerås, VåP5 and VåACV very easily formed a stable suspension and were as well easy to inject.

Further observations of the injection experiments include leaching of the containers by adding water to the top, to simulate precipitation. Chemical parameters will be measured in the leach solutions and also to which degree the fly ash stays in the container will be evaluated. It is important that the fly ash is not washed out too fast and preferably sticks to the mine waste.

Results from the first leaching day (L/S 10) of the laboratory batch mixing of ashes with mine waste (5 and 10 % addition of ash, by weight) are shown in table 4.

It seems like an addition of 10 % fly ash to the mine waste would be sufficient for most of the ashes as almost all of them give a pH above 7. The one exception was however UppB, which only give a pH of 6.2 with 10 % addition (and no alkalinity with 5 % addition). Not that surprising though, as the UppB-ash for instance had free lime content below detection limit (table 1). Two of the experiments were only injected with 2.5 kg fly ash to 50 kg waste rock (5 % addition). These two ashes were Kpbg and StE (table 3). From table 4 it is however clear that for these ashes addition of 5 % should be enough, at least initially. The total amount of neutralizing material will of course have an impact on the longevity of the treatment.

Table 4: Results from laboratory batch mixing of mine waste and fly ashes. Alkaline addition was 5 and 10 %. (m.v.: missing value).

	Alkaline addition	Redox (mV)	El. Cond. ( $\mu\text{S}/\text{cm}$ )	pH	Alkalinity (meq/L)
Mine waste	None	288	905	3.08	0
VåP5	5 %	66	913	6.15	0.32
VåP5	10 %	27	1 014	7.37	0.46
VåACV	5 %	46	851	6.04	m.v.
VåACV	10 %	13	969	7.23	1.32
EonW	5 %	72	853	6.07	0.26
EonW	10 %	45	898	7.21	0.16
EonD	5 %	53	889	7.08	0.06
EonD	10 %	44	904	7.19	0.13
StE	5 %	48	958	7.19	0.15
StE	10 %	33	1 118	8.37	0.23
KorW	5 %	85	829	6.00	0.38
KorW	10 %	63	926	7.06	0.70
KorD	5 %	58	951	7.01	0.66
KorD	10 %	53	975	7.25	0.16
UppG	5 %	74	1 157	6.24	0.18
UppG	10 %	53	1 576	7.09	0.28
UppB	5 %	119	1 461	5.59	0
UppB	10 %	93	1 858	6.24	0.22
Kpbg	5 %	70	993	7.20	0.66
Kpbg	10 %	51	997	7.92	0.46

## CONCLUSIONS

The most important parameter is pH – determining the weathering process, as well as the mobility and distribution of trace metals, formation of solid precipitates (of primarily iron and aluminum) serving as carriers as well as coprecipitating agents. The choice of alkaline neutralizing agent is crucial, considering capacity and pH-buffering ability (as well as alkalinity source – hydroxide or carbonate). The control of iron (chemical state) is of crucial importance.

An important observation from the stabilization studies (study 1) was lowered water flow in fly ash amended barrels compared to barrels amended with other alkaline materials (e.g. lime mud and green liquor dreg), due to formation of hydrous Ca-Si-Al minerals (hard pan). One can also conclude that mixing in distinct layers favor fly ash amended systems, while homogeneous mixing of the materials favor carbonate amended systems

Addition of fly ash to mine waste must not be too low because of depletion of the neutralizing capacity, neither too high because of desorption at high pH.

Problems with injection mainly originated from pre-moistening of the fly ashes, which seem to increase the tendency to separate – difficulties with keeping a stable suspension. However, the two UppB- and UppG-ashes were as well pre-moistened but were still able to keep a relatively stable suspension.

If the free lime content is too high there can be problems with rapid hardening making the injection difficult. Hardening of the ash inside the deposit is though desired as it decreases water flow and keeps the fly ash more permanently inside the deposit (less tendency for washing out).

Summarizing, slurry injection of fly ash to weathered mine waste seems to be a promising remediation method. Still, the injection experiments need a follow-up evaluation regarding how well the fly ash stays in the container and to which degree the fly ash fills out the voids. Also, the chemistry of the leachates from these experiments must be measured during extended time to ensure that no other contaminants are added by the fly ash.

## REFERENCES

- [1] Cravotta III, C.A., Trahan, M.K., "Limestone drains to increase pH and remove dissolved metals from acidic mine drainage," *Applied Geochemistry*, 1999, 14: 581-606.
- [2] Elberling, B., Balic´-Zunic´, T., Edsberg, A., "Spatial variations and controls of acid mine drainage generation," *Environmental Geology*, 2003, 43: 806-813.
- [3] Lefebvre, R., Hockley, D., Smolensky, J., Gélinas, P., "Multiphase transfer processes in waste rock piles producing acid mine drainage. 1. Conceptual model and system characterization," *Journal of Contaminant Hydrology*, 2001, 52: 137-164.
- [4] Elberling, B., Nicholson, R.V., "Field determination of sulphide oxidation rates in mine tailings," *Water Resources Research*, 1996, 32: 1773-1784.
- [5] Nordstrom, D.K., "The effect of sulfate on aluminum concentrations in natural waters: some stability relations in the system  $Al_2O_3$ - $SO_3$ - $H_2O$  at 298 K," *Geochimica et Cosmochimica Acta*, 1982, 46: 681-692.
- [6] Hossner, L.R., Doolittle, J.J., "Iron sulfide oxidation as influenced by calcium carbonate application," *Journal of Environmental Quality*, 2003, 32: 773-780.
- [7] Doye, I., Duchesne, J., "Column leaching tests to evaluate the use of alkaline industrial wastes to neutralize acid mine tailings," *Journal of Environmental Engineering*, 2005, 131: 1221-1229.
- [8] Sartz, L., Bäckström, M., "Reclamation of historical mine waste using alkaline by-products," *In: Northern Latitudes Mining Reclamation Workshop*, Juneau, Alaska, 2007.
- [9] Bäckström, M., Sartz, L., "Mixing of acid rock drainage with alkaline ash leachates – Fate and immobilisation of trace elements," *Water, Air, & Soil Pollution*, 2011, 222: 377-389.
- [10] Li, X.D., Poon, C.S., Sun, H., Lo, I.M.C., Kirk, D.W., "Heavy metal speciation and leaching behaviors in cement based solidified/stabilized waste materials," *Journal of Hazardous Materials*, 2001, A82: 215-230.
- [11] Bertocchi, A.F., Ghiani, M., Peretti, R., Zuca, A., "Red mud and fly ash for remediation of mine sites contaminated with As, Cd, Cu, Pb and Zn," *Journal of Hazardous Materials*, 2006, B134: 112-119.

- [12] Shang, J.Q., Wang, H.L., Kovac, V., Fyfe, J., "Site-specific study of stabilization of acid-generating mine tailings using coal fly ash," *Journal of Materials in Civil Engineering*, 2006, 18: 140-151.
- [13] Xenidis, A., Mylona, E., Paspaliaris, I., "Potential use of lignite fly ash for the control of acid generation from sulphidic wastes," *Waste Management*, 2002, 22: 631-641.
- [14] Hossein, M., Mohamed, A.M.O., Hassini, F.P., Elbadri, H., "Ettringite formation in lime-remediated mine tailings: II. Experimental study," *CIM Bulletin*, 1999, 92: 75-80.
- [15] Bulusu, S., Aydilek, A.H., Rustagi, N., "CCB-based encapsulation of pyrite for remediation of acid mine drainage," *Journal of Hazardous Materials*, 2007, 143: 609-619.
- [16] Gilbert, S.E., Cooke, D.R., Hollings, P., "The effects of hardpan layers on the water chemistry from the leaching of pyrrhotite rich tailings material," *Environmental Geology*, 2003, 44: 687-697.
- [17] Davis, A., Eary, L.E., Helgen, S., "Assessing the efficacy of lime amendment to geochemically stabilize mine tailings," *Environmental Science & Technology*, 1999, 33: 2626-2632.
- [18] Bäckström, M., Sädbom, S., "Risk assessment of historical mine waste using chemical analysis and ocular mineral/rock classification," In: *9<sup>th</sup> International Congress for Applied Mineralogy*, Australasian Institute of Mining and Metallurgy, Publication Series 8/2008: 85-90.
- [19] Ahmaruzzaman, M., "A review on the utilization of fly ash," *Progress in Energy and Combustion Science*, 2010, 36: 327-363.
- [20] Pérez-López, R., Nieto, J.M., Álvarez-Valero, A.M., Almodóvar, G.R., "Mineralogy of the hardpan formation process in the interface between sulfide-rich sludge and fly ash: Applications for acid mine drainage mitigation," *American Mineralogist*, 2007, 92: 1966-1977.
- [21] Wikman, K., Berg, M., Andreas, L., Lagerkvist, A., Jannes, S., Tham, G., Sjöblom, R., "Grouting of fly ash in sanitary landfills," *Värmeforsk Rapport 830*, 2003, in Swedish.