Effect of bulk use of power plant fly ash in coal mine workings on water quality in the Upper Silesian Coal Basin (USCB, Poland)

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Abstract: The environmental evaluation of bulk use of fly ash (FA) in deep coal mines in the form of dense mixtures with mine water has been discussed on the background of the aquatic environment protection requirements, as well as qualitative and quantitative characteristics of mine waters. The effect of major parameters such as low and high alkalinity of FA and salinity of mine water as components of FA: mine water mixtures, as well as of hydrogeological conditions in the mining area has been exemplified in the case studies for the Szczyglowice and Boleslaw Smialy coal mines (USCB, Poland). It has been shown that use of FA mixtures with saline mine water in coal mines results in reduction of mine water discharge to the receiving surface waters and of loads of the majority of contaminants contained in the saline mine waters used for the mixture preparation. These mixtures may though exert an adverse effect on the usable high quality mine waters. The most environmentally beneficial and safe option was found to be the utilization of FA mixtures with saline mine water in dry mine workings insulated from the recoverable groundwater resources.

1 INTRODUCTION

During the last decade fly ash (FA) utilization in deep coal mines of the Upper Silesian Coal Basin (USCB) in Poland has become a routine process. The main direct purposes of FA application underground are liquidation and sealing of mined out and abandoned workings and shafts, backfilling as well as construction of stoppings for fire prevention and control, methane control and reduction of greenhouse effects caused by methane release to the atmosphere, simplification of a ventilation system, and reduction of surface deformations. In this area, around 4.0 million tons of FA is being utilized annually (State Environmental Protection Inspectorate, 1997). Up to the end of 1994, coal mines of the USCB used at least 17.4 million tons of FA (State Environmental Protection Inspectorate, 1995). By the end of 1999 the amount of FA used in deep mines has been estimated for about 34 Mt and continues to grow in time with the same intensity limited by the availability of this waste. The scale and experience in FA use underground places Poland at the top of the countries, which produce comparably high amounts of coal combustion waste, with respect to the percentage of its use; in this particular area of FA application Poland has no competitors in the world.

In Polish practice, FA is being used underground in the form of dense (low-water) FA mixture with mine water. The mixture is being prepared at the surface and transported underground gravitationally by pipelines to an outlet behind the barrier (stopper) in the backfilled working. The mine water: FA ratio is determined by the transportability of the mixture, the distance of the outlet from the retention tank at the surface, and the time of the mixture solidifying. The most frequent mine water: FA ratio is 1: 1, up to 0.8: 1 by weight. The deposited mixture undergoes gradual dewatering. An excess of water joins the mine drainage system and is pumped to the surface. Partially or thoroughly, the residual water is directed back to the circuit of mine water: FA mixture. The surplus outflow is discharged to the surface recipients (rivers) either directly, or through the mine water-collecting pipeline.

Utilization of large quantities of CCW in underground mine workings in the form of dense FA: mine water mixture creates entirely new environmental issue. For its evaluation, adequate criteria should be applied, which consider the contamination potential of both components, i.e. mine water and FA, contaminant discharge in the outflow of surplus water from of the mixture, as well as the general ground- and surface water protection requirements and hydrogeological conditions in the mining area. Environmental evaluation of FA use underground should thus comprise: (i) Short- and long-term (life cycle) prognosis of contaminant loads release/retention balance from mine water: FA mixture, in compliance with its disposal environment; (ii) Characterization of hydrogeological and hydrogeochemical conditions in working or abandoned mines with regard to protection requirements of major groundwater basins (MGWB) and usable ground water horizons (UGWH); (iii) Prognosis of post-closure hydro-geological and hydrogeochemical conditions in the mine where FA was used.

The major criterion for evaluation of the effect of FA: mine water mixtures use underground on the aquatic environment should be the balance of actual input and output pollutant loads in the mixture, with regard to the quality requirements of the ground water and surface recipient. The load-based criteria assure obtaining the objective data on either adverse or beneficial environmental effect of FA:mine water mixtures used in mine workings. These criteria permit separate evaluation of the amount of pollutants introduced to the system by mine water and released or retained by fly ash. The positive or adverse environmental impact is thus evaluated as negative or positive load balance in outflow from the mixture compared to the load introduced to the mixture with mine water.

On the grounds of the above criteria and procedure, extensive testing and studies on the environmental evaluation of FA use in deep mines in different hydrogeological conditions was conducted in 1993-1996. The assessment comprised FA originating from the three power plants (Rybnik, Laziska and Opole), being used in 24 coal mines of the USCB either without an admixture of flue gas desulfurization products termed as “pure” FA, or with admixture of products from desulfurization processes.

“Pure” FA (without an admixture of desulfurization products) is the most abundant waste in electric utilities, which do not use desulfurization of flue gases, and in the ones using wet desulfurization process that is predominant in the USA, Germany and most of the other countries using desulfurization of flue gases.

Below, an environmental effect of "pure" FA use in the different hydrogeological conditions has been discussed. The evaluation of this effect on the ground- and surface waters has been presented on the background of the general requirements of the aquatic environment protection, as well as qualitative and quantitative characteristics of mine waters.

2 HYDROGEOLOGICAL CONDITIONS *VS* WATER PROTECTION REQUIREMENTS

2.1 Ground Water Protection Requirements

In the area of FA utilization underground, the critical protection areas (CPA) of the major groundwater aquifers (MGWA), also in Carboniferous strata, should be considered and protected against contamination from this source. FA utilization at any rate may not pose a threat to the usable ground water resources. Kleczkowski (1990) defined usable groundwater horizons (UGWH) and major groundwater aquifers (MGWA) on the basis of the qualitative and quantitative criteria. Groundwater aquifers defined as MGWA are the fragments of UHGW of better hydrogeological conditions. With respect to qualitative criteria, two basic classes of water have been distinguished: I – to be used for drinking water supply; II – not considered to be used for drinking water supply. Waters belonging to the Class I comprises 4 sub-classes (a, b, c, d) depending upon the need for water preparation.

That either UGWHs or MGWAs are not jeopardized by FA utilization is to be confirmed by the environmental impact assessment (EIA).

2.2 Characteristics of Mine Waters

Mine waters are a component of FA: water mixture and therefore exert a considerable effect on its properties, environmental behavior and pollution potential. Optimization of the environmental effect of FA use underground requires thus adequate mine water management.

Waters occurring in the Carboniferous strata in the USCB represent different chemical composition and total dissolved solids (TDS) ranging over wide limits from 0.1 to 230 g/dm^3. It reflects hydrogeological zonality in the stratigraphic column typical for sedimentation basins, which is characterized by the general trend of downward increase of salinity independent from the age of the stratigraphic column. With respect to chemical composition, type and salinity of mine waters, three corresponding vertical hydrochemical zones can be distinguished: (I) infiltration, (II) mixed and (III) connate waters (Różkowski, 1995).

Water inflow to mines of the USCB ranges from 0.5 to 7.4 m^3/min). The mines were classed by Wilk (1965) as the ones of high (>5 m^3/min), moderate (from >2 to ≤ 5 m^3/min) and low water inflow (≤ 2 .0 m^3/min).

Discharge of saline mine waters to the low-flow surface receiving waters in the USCB area results in the off-class deterioration of their quality. Therefore, the reduction of discharged contaminant loads becomes critical for the environment protection and mine economy.

3 EFFECTS OF DENSE MINE WATER: FA MIXTURE USE IN MINE WORKINGS ON CONTAMINANT RELEASE AND DISCHARGE

3.1 General Trends

Utilization of FA in mine workings in the form of dense mine water: FA mixtures, besides already mentioned benefits for the environment, may exert different effect on the mine water quality and contaminant loads discharged to the receiving surface waters, depending upon the chemical composition of FA and mine water used for mixture preparation, hydrogeochemical and technological properties of the mixture, and hydrogeological characteristics of the mining area.

In general, combustion processes result in concentration of the most of macro-elements and trace metals in about an order of magnitude compared to the content in burned coal and in the lithosphere. Elemental composition of FA from Polish and other European hard coal-fired power plants shows high similarity that permits a considerable generalization of observations (Twardowska, 2000). "Pure" FA belongs to alkaline aluminum silicate material (van der Sloot et al., 1984). The ratio $CaO+MgO/SO_3 + 0.04\ Al_2O_3$, which indicates an extent of alkalinity or buffering capacity of FA, varies in the wide range, from <1 to >4 (the most frequently 1.3-3.9). In this respect, FA may be eventually classed as low-alkalinity (LA-FA) or high-alkaline (HA-FA), though the border between these two kinds is difficult to be univocally defined. Concentrations of trace metals in "pure" FA show declining order [10^3 mg/kg] (Ba>Sr>Mn>V) >> [≥10^2 mg/kg] (Rb, Cr, Zr, Ce, Zn, Ni, Cu) > [>10 mg/kg] (Co, Pb, La,Y, Nd, Sc, Th, Cs, As) > [≅ 10 mg/kg] (Sm, Be, U, Mo, Br, Sb) > [<10] (Yb, Hf, Bi, W, Se) > [10^{-1} mg/kg] (Eu, Ta, Tb, Lu, Hg, Cd, Ag) >> [10^{-2} mg/kg] (Au, Ir). Fluoride occurs in amount of 90-120 mg/kg. High metal concentration is an adverse property of this material. A positive characteristics of FA is its high water binding capacity, which accounts for 50 % up to over 70 % wt. related to the FA mass.

In general, all the mixtures of "pure" FA with mine water after solidification (16-24 days) display penetration resistance R values, ranging from 1000 to 1200 kPa; i.e. an order of magnitude higher than the ones of natural cohesive soils such as boulder clay (R=190 kPa). Therefore, the FA:water mixtures after solidification showed excellent sealing properties against air penetration.

The values of hydraulic conductivity for “pure” FA is at the level of $k \geq 10^{-8}$ m/s and mostly does not fulfill the criteria of impermeability both with respect to the horizontal (Pazdro and Kozerski, 1990) and vertical water flow (Witczak and Adamczyk, 1994). The leaching and transport of contaminants from the FA layer to the ground water by the percolating water can thus occur.

The effect of major parameters such as low and high alkalinity of FA and salinity of mine water as components of FA: mine water mixtures, as well as of hydrogeological conditions in the mining area has been exemplified here in the case studies for the Szczyglowice and Boleslaw Smialy coal mines (USCB, Poland), which utilize FA from the Rybnik (LA-FA) and Laziska (HA-FA) power plants and low- and high TDS mine water from different seams for preparation of dense FA mixtures.

3.2 Chemical composition of leachate from dense mine water: FA mixtures

The effect of FA characteristics, in particular of its alkalinity, on the leachate composition is exemplified in Tables 1 and 2. The typical changes compared to the input mine water common for both low- and high-alkalinity FA: mine water systems consist of transformation of Ca-Mg hardness in the input mine water into predominantly Ca hardness in leachate, increase of K, and mostly considerable increase of output COD. Amphoteric trace elements and oxyanions distinctly increase in the leachate especially Cr, and Mo. High enrichment of fluoride in outflow was also observed.

In general, trace element concentrations in leachate follow leaching patterns caused by solubility/stability criteria, pH being the main controlling factor (van der Sloot et al., 1991). The ionic strength and chemical composition of the solution resulting from the interaction of mine water with FA exerts considerable effect on trace element release or binding and results in substantial diversity in leaching behavior of FA.

Some differences in alteration of mine water chemical composition, which result from the contact with FA in low-alkaline and high-alkaline systems were found to be specific for these systems.

In low-alkalinity FA: saline mine water systems (Table 1), the chemical composition of leachate is dictated by equilibrium with gypsum. The typical transformations of the output leachate from the mixture compared to the input mine water comprise frequent moderately alkaline pH; decrease of carbonate contents in parallel with increase of sulfate to the concentration dictated by the equilibrium with gypsum; frequent decrease of chloride and sodium concentrations due to complexation at Cl-Na type of input waters, which results in the adequate reduction of TDS; increase of nitrogen (N) compounds. Due to pH range within the stability field of the majority of trace metals, weak metal release or reduction of Ba (due to precipitation of $BaSO_4$), Cd, Co, Cu, Fe, Mn and Zn occurs in the output leachate.

Table 1 Concentrations and load balance of dissolved constituents in the input high-TDS mine water (Szczyglowice mine) and output leachate from mine water: high alkalinity FA mixture 1:1 wt., and leachability of constituents from the solidified material "Pure" low alkalinity fly ash (LA-FA) from the Rybnik power plant

Parameters, Constituents	Mine water – Szczyglowice mine Input 1.0 m^3 Mg^{-1}		Leachate from water - fly ash mixture 1:1 Output 0.536 m^3 Mg^{-1}		Leached (+) or bound **(-)** loads	Solidified mixture - Leachable load
Parameters	$C_{in,}$ Mg dm^{-3}	L_{in} g Mg^{-1}	$C_{out,}$ mg dm^{-3}	$C_{out,}$ Mg dm^{-3}	$\Delta L = L_{in} - L_{out}$ g Mg^{-1}	ΣL_{1-3} g Mg^{-1}
µS cm^{-1}	176300		90000			
pH	7.77		7.15			7.65-8.72
Alkalinity, meq dm^{-3}	2.40	2.40	0.6	0.32	**-2.08**	12.5
Hardness, meq dm^{-3}	195.37	195.37	270.65	145.1	**-50.30**	183.90
Hardness Ca	114.37	114.37	230.61	123.6	9.23	180.57
Hardness Mg	**81.00**	**81.00**	**40.05**	**21.47**	**-59.53**	3.63
Macro-constituents						
Ca	2291.9	2291.9	4621.35	2476.9	185.14	3618.6
Mg	**985.0**	**985.0**	**487.0**	**261.03**	**-723.97**	44.05
Na	26664	26664	32899	176339	**-9030**	17691
K	865	865	904.1	484.6	**-380.4**	770.65
NH_4^+- N	3.90	3.90	20.0	10.72	6.82	1.70
NO_3^-- N	0.05	0.05	0.681	0.365	0.315	1.705
Cl	55260	55260	62628	33569	**-21691**	29404
SO_4^{2-}	392.4	392.4	1992.5	1068.0	675.6	2108.4
HCO_3^-	**146.4**	**146.4**	**36.61**	**19.62**	**-126.82**	732.2
CO_3^{2-}	0.00	0.00	0.00	0.00	0.00	15.0
OH^-	0.00	0.00	0.00	0.00	0.00	0.00
PO_4^{3-}	**0.08**	**0.08**	**0.03**	**0.016**	**-0.064**	0.235
TDS	92771	92771	107162	57439	**-35332**	54820
COD	360.2	360.2	3988.4	2137.68	1777.6	5032
Trace elements						
Al.	<0.06		<0.06			ND
Ba	**1.219**	**1.219**	**0.774**	**0.42**	**-0.80**	ND
Cd	0.13	0.13	0.25	0.134	0.004	<0.075
Co	**0.66**	**0.66**	**0.51**	**0.27**	**-0.39**	0.275
Cr	0.13	0.13	2.48	0.048	**-0.082**	0.75
Cr(VI)	0.0015	0.0015	0.006	0.0032	0.002	0.49
Cu	0.11	0.11	0.13	0.07	**-0.04**	0.10
Fe	**0.54**	**0.54**	**0.46**	**0.25**	**-0.29**	0.30
Mn	**1.54**	**1.54**	**0.15**	**0.08**	**-1.46**	0.10
Mo	ND		ND			ND
Ni	**0.88**	**0.88**	**0.60**	**0.32**	**-0.558**	0.10
Pb	**0.92**	**0.92**	**0.63**	**0.34**	**-0.582**	0.275
V	<0.01		<0.01			ND
Zn	**0.31**	**0.31**	**0.04**	**0.02**	**-0.289**	0.175

ND - not determined
Constituents showing the reduction of concentrations and/or loads in leachate compared to the input mine water are bold

Table 2 Concentrations and load balance of dissolved constituents in the input high-TDS mine water (Boleslaw Smialy mine) and output leachate from mine water: high alkalinity FA mixture 1:1 wt., and leachability of constituents from the solidified material "Pure" high alkalinity fly ash (HA-FA) from the Laziska power plant

Parameters, Constituents	Mine water – Boleslaw Smialy mine Input 1.0 $m^3 Mg^{-1}$		Leachate from water - fly ash mixture 1:1 Output 0.274 $m^3 Mg^{-1}$		Leached (+) or bound (-) loads	Solidified mixture - Leachable load
Parameters	C_{in}, Mg dm^{-3}	L_{in} g Mg^{-1}	C_{out}, mg dm^{-3}	C_{out}, Mg dm^{-3}	$\Delta L = L_{in} - L_{out}$ g Mg^{-1}	ΣL_{1-3} g Mg^{-1}
μS cm^{-1}	74300		75500			
pH	7.36		12.11			7.64-7.82
Alkalinity, meq dm^{-3}	3.35	3.35	10.30	3.78	0.03	11.75
Hardness, meq dm^{-3}	94.80	94.80	157.76	57.85	**-36.95**	100.73
Hardness Ca	34.94	34.94	157.60	57.79	22.85	91.35
Hardness Mg	**59.90**	**59.90**	**0.16**	**0.0058**	**-59.84**	9.38
Macro-constituents						
Ca	700.17	700.17	3159.5	1158.6	458.43	114.10
Mg	**728.00**	**728.00**	**1.30**	**0.48**	**-727.52**	12854
Na	22884	22884	22839	8375	**-14509**	809.5
K	369.3	369.3	880.6	322.9	**-46.4**	7.00
NH_4^+- N	**31.92**	**31.92**	**9.38**	**3.44**	**-28.48**	0.07
NO_3^-- N	**0.186**	**0.186**	**0.009**	**0.0033**	**-0.183**	0.46
Cl	38400	38400	40580	14881	**-23519**	21277
SO_4^{2-}	**1126.1**	**1126.1**	**1117.0**	**409.6**	**-716.5**	2624.1
HCO_3^-	204.41	204.41	0.00	0.00	**-204.41**	716.95
CO_3^{2-}	0.00	0.00	30.01	11.00	11.00	0.00
OH^-	0.00	0.00	158.17	57.99	57.99	0.00
PO_4^{3-}	0.001	0.001	0.040	0.0036	0.0026	0.20
TDS	64089	64089	69368	25437	**-38652**	41200
COD	**946.4**	**946.4**	**364.1**	**133.5**	**-812.9**	4611.5
Trace elements						
Al.	**0.203**	**0.203**	**<0.06**		**-0.203**	ND
Ba	0.053	0.053	0.310	0.11	0.057	ND
Cd	0.07	0.07	0.10	0.037	**-0.033**	0.45
Co	0.44	0.44	0.50	0.18	**-0.26**	0.20
Cr	0.05	0.05	0.34	0.12	0.07	1.45
Cr(VI)	<0.001		0.097	0.036	0.036	1.34
Cu	0.10	0.10	0.09	0.033	**-0.067**	3.25
Fe	0.36	0.36	0.41	0.15	**-0.21**	1.13
Mn	0.07	0.07	0.09	0.033	**-0.037**	0.20
Mo	<0.025		1.221	0.45	0.45	ND
Ni	**0.62**	**0.62**	**0.31**	**0.11**	**-0.51**	0.40
Pb	**0.61**	**0.61**	**0.56**	**0.21**	**-0.40**	0.60
V	<0.01		<0.01			ND
Zn	**0.14**	**0.14**	**<0.005**		**-0.14**	0.45

ND - not determined
Constituents showing the reduction of concentrations and/or loads in leachate compared to the input mine water are bold

Ni concentrations are high due the vast stability field in solution in a broad pH range and high content in FA.

In high-alkalinity FA: mine water systems (Tables 2, 3), chemical composition of leachate is governed by carbonate equilibria, which determine a pattern of the qualitative transformations of the input mine water. The most characteristic trends in these systems are an increase of pH value, up to pH>12, alkalinity, carbonate hardness, Cl and Na concentrations, the higher, the lower is Cl-Na salinity of the input mine water, and adequate increase of TDS; decrease of sulfate concentrations and hardness, the deeper, the higher are SO_4 concentrations in the input mine water; frequent distinct decrease of nitrogen compounds (ammonia and nitrate). Concentrations of trace metals in leachate strongly depend upon their stability field at elevated pH. Most of metals in such systems with "pure" high alkalinity FA show a general moderate increase. Trace metal concentrations in the leachate usually somewhat exceed the maximum permissible concentration level for drinking water (MCL). The deterioration of output water quality is considerably higher if low-TDS good quality mine water is used for mixture preparation due to a massive release of constituents from FA (Table 3 *vs* Table 2).

The decrease of N compounds and sulfate contents in leachate from high alkaline FA: mine water mixtures or the reduction of Cl, Na and TDS in leachate from low alkaline FA: mine water mixtures is not an explicit rule and in some systems does not occur, which is due to the variety of chemical composition and physiochemical parameters of both FA and mine waters used for mixture preparation.

3.3 Load balance

Generally, the surplus water outflow from mine water: FA mixture (leachate) in the dewatering stage is of worse quality than that of the input mine water, Nevertheless, the permanent binding in high-TDS mine water: FA mixture up to 75 % wt. of input water results in a considerable reduction of the discharged loads of contaminants compared to those in the input mine water, including major macro components like chloride, hardness, Na, K, TDS and COD, N compounds and in high alkaline systems or at high sulfate input water also sulfate. Almost all trace metal loads except Cr_t, Cr(VI) and Mo also show reduction (Tables 1, 2).The most environmentally beneficial effect is the high reduction of discharged contaminant loads resulting from the preparation of FA mixtures of highly saline, acidic, high trace metal mine waters from the deep seams at the ratio assuring transportability at the minimum leachate, usually 1:1 or less. The adverse effect of “pure” FA use underground is an increase of pH value in excess outflow up to strongly alkaline pH≥12 in the high alkalinity systems and mobilization of amphoteric metals like Cr and Ni. Oxyanions such as Mo show high mobility in a wide range of pH, both in neutral and alkaline systems. The released excessive loads, though, can be effectively minimized by the optimization of the mine water: FA ratio.

The application of a better quality low-TDS mine water fit for any other purpose for preparation of mine water: FA mixtures should be avoided in order to protect usable ground-water resources and because of a strongly reduced or even completely lacking environmentally beneficial effect of contaminant binding. A comparison of the load balance for a mixture of low- and high-TDS mine water (Table 3 *vs* 2) clearly shows the domination of release over binding of almost all measured macro-constituents and trace elements if low-TDS mine water is being used for a mixture preparation (Table 3). If moderate to high-TDS saline mine water is used, the binding effect prevails with respect to the both macro- and trace constituents (Tables 1, 2). If no other water is available, the maximum technologically possible reduction of mine water: FA ratio would allow achieving a substantial decrease of the leachate volume. This also decreases the excessive loads of contaminants in leachate that are to be discharged to the water: FA mixture preparation circuit, which can be separated from a general mine dewatering system if the released loads adversely affect the discharged water quality.

3.4 Effect of hydrogeological conditions on contaminant release

In the case of application FA in the form of dense low-ratio mine water: FA mixture in dry mine workings insulated either from the infiltration zone of the recoverable ground water resources or from the inflow of mine waters from the upper seams, the leachate is limited entirely to the outflow of the excess water from the deposited mixture. Under the complicated hydrogeological conditions of mines, further leaching of FA mixtures by infiltration water either from the surface or from the upper seams may occur in wet seams and in the post-closure period due to water logging of dry seams.

The solidified mixture of "pure" FA contains considerable loads of leachable components that can be released to the percolating water (Tables 1-3). These additional loads will particularly severely affect low-TDS good quality waters in the zone of direct feeding of usable recoverable resources of MGWAs and UHGWs. In the discussed examples the endangered usable waters occur in the mining area of the Boleslaw Smialy mine that comprise Carboniferous MGWA 1 (Łaziska) and UGWH 3 (Dębieńsko-Ornontowice). The predominance of release over binding in the dewatering stage and leaching of contaminants from the deposited mixture by the infiltration water cause a general adverse effect of FA deposition in wet workings of this mine (Table 3).

The load balance in the dewatering stage (Tables 1-3) and the long term practice of FA utilization in deep mines shows, that the most environmentally beneficial and safe option is utilization of FA mixtures with saline mine water in dry mine workings insulated from the recoverable ground water resources. Use of saline waters intensifies and accelerates solidification of FA layer, which is an additional advantage. Such hydrogeological conditions occur in the mining area of the Szczyglowice mine that belongs to dry mines (total inflow in 1993 accounted for 0.45 m^3/min, of which brines are predominant.

Table 3 Concentrations and load balance of dissolved constituents in the low-TDS input mine water (Boleslaw Smialy mine) and output leachate from mine water: high alkaline FA mixture 1:1 wt., and leachability of constituents from the solidified material Pure high alkaline fly ash (HA-FA) from the Laziska power plant

Parameters, Constituents	Mine water – Boleslaw Smialy mine Input 1.0 m^3 Mg^{-1}		Leachate from water - fly ash mixture 1:1		Leached (+) or bound **(-)** loads	Solidified mixture - Leachable load
			Output 0.426 m^3 Mg^{-1}			
Parameters	C_{in}, Mg dm^{-3}	L_{in} g Mg^{-1}	C_{out}, mg dm^{-3}	C_{out}, Mg dm^{-3}	$\Delta L = L_{in} - L_{out}$ g Mg^{-1}	ΣL_{1-3} g Mg^{-1}
µS cm^{-1}	3600		12820			
PH	7.80		12.71			7.87-7.73
Alkalinity, meq dm^{-3}	1.20	1.20	18.30	7.81	6.61	12.00
Hardness, meq dm^{-3}	15.00	15.00	82.52	35.21	20.21	46.97
Hardness Ca	7.11	7.11	82.50	35.20	28.09	35.45
Hardness Mg	**7.90**	**7.90**	**0.02**	**0.0085**	**-7.89**	11.52
Macro-constituents						
Ca	142.56	142.56	1652.7	705.21	562.65	710.0
Mg	**95.5**	**95.5**	**0.21**	**0.089**	**-95.41**	140.1
Na	506.3	506.3	1877.5	801.13	294.83	634.2
K	39.19	39.19	258.1	110.13	70.94	353.5
NH_4^+- N	**4.90**	**4.90**	**2.94**	**1.25**	**-3.65**	5.11
NO_3^-- N	1.077	1.077	0.033	0.014	**-1.063**	0.22
Cl	540.6	540.6	4140.0	1766.5	1225.9	1364.2
SO_4^{2-}	979.9	979.9	629.2	268.5	**-711.4**	1855.7
HCO_3^-	73.22	73.22	0.00	0.00	**-73.22**	732.2
CO_3^{2-}	0.00	0.00	18.00	7.68	7.68	0.00
OH^-	0.00	0.00	301.04	128.44	128.44	0.00
PO_4^{3-}	0.004	0.004	0.026	0.011	0.007	0.37
TDS	2890	2890	9116	3890	999.8	6880
COD	67.6	67.6	260.0	110.94	43.34	961.2
Trace elements						
Al.	**0.306**	**0.306**	**<0.06**		**-0.306**	ND
Ba	0.030	0.030	0.124	0.053	0.023	ND
Cd	<0.005		<0.005			0.35
Co	0.02	0.02	0.07	0.029	0.009	0.05
Cr	0.01	0.01	0.24	0.102	0.092	2.35
Cr(VI)	<0.001		0.223	0.095	0.095	1.57
Cu	<0.005		0.02	0.0085	0.0085	0.50
Fe	0.03	0.03	0.08	0.034	0.004	1.45
Mn	<0.005		0.02	0.0085	0.0085	0.05
Mo	<0.025		1.345	0.57	0.57	ND
Ni	0.03	0.03	0.17	0.072	0.042	0.15
Pb	0.02	0.02	0.12	0.051	0.031	0.25
V	<0.01		<0.01			ND
Zn	<0.005		<0.005			0.30

ND - not determined

Constituents showing the reduction of concentrations and/or loads in leachate compared to the input mine water are bold

In addition to the direct implications of FA use on the quality and quantity of mine water and on the contaminant loads discharged to the surface receiving waters, a beneficial side effect of dense FA mixtures use in deep coal mines workings on the attenuation of sulfide oxidation in the mined out Carboniferous seams due to sealing against air penetration should be also considered.

4 CONCLUSIONS

Utilization of FA in mine workings in the form of dense saline mine water: FA mixtures results in reduction of mine water discharge to the surface receiving waters and of loads of the majority of contaminants contained in the saline mine waters used for the preparation of "pure" FA: mine water mixtures.

The output concentrations of the majority of contaminants are higher in leachate than in the input saline mine water as a result of the release from FA. The output loads of these contaminants in leachate (Cl, Na, TDS, trace metals) are though considerably lower than the respective input loads in mine water used for preparation of mixtures with FA, mainly due to the permanent binding of water in the solidifying mixture that accounts roughly from 50 % up to 75 % wt. related to the FA mass, along with a respective load of dissolved constituents. In some cases, also reduction of concentrations of some constituents in the excess outflow occurs due to precipitation or sorption. This way utilization of coal combustion waste underground has a positive effect on the water quality of surface waters receiving mine drainage.

The results of studies display a general adverse effect of mine water:FA mixtures exposure to vertical infiltration of water due to the contact with the recoverable ground water resources or with their feeding zone. Use of a good quality low-TDS water for mixture preparation also results in unfavorable domination of load release over binding. The practice of FA utilization in underground mine workings shows that the most environmentally beneficial and safe option is utilization of FA mixtures with saline (high-TDS) mine water in dry mine workings insulated from the recoverable ground water resources.

Thus, in every case of the planned use of FA in mine workings, the long-term prognosis of the environmental effect of FA utilization in the actual hydrogeological conditions should be carried out to avoid unnecessary risk both to the usable groundwater and the receiving surface waters.

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Wpływ stosowania emulgatów z pyłów z elektrowni do wypełniania wyrobisk poeksploatacyjnych kopalń węgla kamiennego na jakość wód kopalnianych w Górnośląskim Zagłębiu Węglowym, Polska

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Streszczenie: W artykule rozpatrzono wpływ stosowania dużych ilości pyłów lotnych (FA) do wypełniania wyrobisk górniczych na ilość i jakość wód kopalnianych. W rozważaniach uwzględniono wpływ głównych parametrów (FA) takich jak niska i wysoka zasadowość pyłów, zasolone wody kopalniane oraz warunki hydrogeologiczne badanych kopalń Szczygłowice i Bolesław Śmiały (GZW, Polska). Udowodniono, że użycie mieszaniny FA ze słoną wodą kopalnianą powoduje zmniejszenie ilości odprowadzanych wód kopalnianych do wód powierzchniowych oraz zmniejszenie ładunku zanieczyszczeń. Mieszaniny te mogą jednak mieć niekorzystny wpływ na wykorzystywanie wód kopalnianych do celów pitnych. Najbardziej optymalnym i bezpiecznym rozwiązaniem jest składowanie mieszaniny FA ze słoną wodą kopalnianą w starych zrobach.