The 20th International Conference on
Transport and Sedimentation of Solid Particles
26–29th September 2023, Wroclaw, Poland

ISSN 0867-7964 ISBN 978-83-7717-392-3

FILLING OF UNDERGROUND VOIDS WITH FY ASH – WATER SLURRIES AS A CONTRIBUTION INTO THE REDUCTION OF SALINE WATERS DISCHARGE FROM COAL MINES INTO THE ODRA RIVER

Grzegorz Strozik, Marcin Popczyk

DOI: 10.30825/4.14-23.2023

Silesian University of Technology, Faculty of Mining, Safety Engineering 7 Industrial Automation, Akacemicka 2, 44-100 Gliwice, Poland, gstrozik@polsl.pl, mpopczyk@polsl.pl

ABSTRACT: Drainage and discharge of mine waters belong to main environmental issues that must be appropriately addressed by underground coal mining industry. Saline mine waters from both active and already closed mines contribute the environmental risks for rivers and their catchments. Increasing average depth of mining works and necessity of drainage of numerous closed mines results in increasing amounts of chlorides and sulphates being introduced into water environments, even then coal production of Polish mining industry is decreasing. Majority of mines waters are discharging directly to watercourses and the only significant environmental protection measure is control of the concentration of salt in main rivers. Balance of mine waters and $Cl^{-} + SO_4^{-}$ ions demonstrates the weight of this issue and gives a background, on which technology of filling of underground voids has been discussed as a method, which, under several conditions, may reduce the discharge of brines and highly salinized mine waters (mineralisation above 42 g/dm^3) by about 30%. Although technology of filling of voids with mixtures of water and finely grained solids (mostly fly ash) is well known and adopted by most of the coal mines, its potential in reduction of saline waters discharge is being wasting due to inconsequence in its use and underestimating its value in terms of saline waters management. Influence of water's salinity on the physical properties of the fill, as well as benefits gained by the coal mines as result of filling of voids, show that these operations should be conducted in the possibly largest extent, limited only by availability of fly ash and volume of voids, being created as result of coal extraction.

KEY WORDS: mine waters management, saline waters discharge, filling of underground voids, fly ash water mixtures, environment protection, protection of Odra river.

1. INTRODUCTION

In 2022, an ecological disaster occurred in the waters of the Odra River related to the bloom of golden algae, *prymnesium parvum,* (IOS-PIB, 2022).The presence of algae in some tributaries of the upper Oder River was also found in 2023. So far, no clear cause for their mass occurrence has been established. However, it can be assumed with high probability that this event was caused by the combined influence of at least several factors. The main source of pollution (mainly salinity) of the Odra waters is the discharge of saline water from hard coal mines in the Upper Silesian Coal Basin. It is also important that the waters of the Oder carry a certain load of salt from the border with the Czech Republic, coming from the mines of the Ostrava-Karviná Coal Basin.

Mine waters from Carboniferous rock mass are contaminated above all else by chlorides and sulphates (Policht-Latawiec, 2014). Large volumes of mine water drainage as well as high concentration of salts heavily affect quality of watercourses and resources, water dependent ecosystems and overall environmental standards in the range of influence of contaminated water bodies (Molenda, 2014; Zgórska et. al., 2016). The problem is of all the more importance that it is not occurs only locally in the USCB, but one should keep in mind that all the mine waters are discharging, via regional watercourses, into two main rivers of Poland (Odra and Vistula), which flow more than 500 km northwards to Baltic See across the country (Policht-Latawiec, 2014). However yearly production of hard coal in USCB decreased strongly to round 55 million tons in 2022 that equals round a half of the output noticed 25 year ago, discharge of saline waters and load of salts from coal mines do not follow this trend and remain constant or even slightly increase.

Although there are not exists any solutions, which are able to solve the problem comprehensively, each available measure should be taken under consideration to reduce the amounts of salinized mine waters pumped from coal mines. Filling of mine voids with the use of mine waters represents practically adoptable technique of reduction of salt waters input into environment.

2. BALANCE OF MINE WATERS IN USCB

Currently in USCB operate 20 active coal mines, 8 mines are currently under decommissioning stage, 17 mines have been permanently closed without necessity for further drainage of mine waters, in other 16 closed mines drainage is still conducting within a central system of mine drainage (CZOK), created for the purpose of the protection of existing collieries (Bondaruk et. al., 2015,). Saline water from liquidated hard coal mines reaches the catchment areas of the Vistula and Odra rivers. In average the pumps stations of CZOK discharge approximately 100 million m^3/year of mine waters with average salts concentration of 3.4 g/dm^3. In 2022, 61.68 million m^3 of mine waters with average salinity of 2.8 g/dm^3 was discharged into the Vistula River catchment and 31.8 million m^3 of water with a salinity of 4.6 g/dm^3 was discharged into the Odra River (Matysik, 2018; Konsek & Czapnik, 2020).

Data in Table 1, collected from the years 2016 - 2021, demonstrate that by decreasing total coal output by round 22%, the discharge of waters in terms of volume and total mass of chlorides and sulphates is increasing. Existing trend is clear when presented graphically, see Figure 1. Data about saline waters discharge from coal mines in Table 1 do not include mine waters from three coal mines located outside the area of USCB.

Amounts of chlorides and sulphates being pumped out from the mines depend on their location on the hydrogeological map of USCB. Mines located in northern part of USCB participate in substantially smaller part of total output of saline waters than in its southern region. However, the northern area is densely urbanized, the number of mines is higher, and the saline waters are discharging mainly to smaller watercourses than in southern part of USCB, so the environmental impacts of saline waters are also noticeable significant (Molenda, 2014; Zgórska et. al., 2016; Gruszczyński et. al. 2014).

Quality of waters in main rivers in USCB is additionally affected by dischargers from the coal mines in Czech part of USCB (Harat et. al., 2015). Water in Odra River at the southern border of Poland contains already up to 350 mg/dm^3 of chlorides and 200 mg/dm^3 of sulphates, what creates unfavourable initial conditions for protection of the Odra river waters against exceeded concentrations of salt, however most of the Polish coal mines operate in the catchment of Vistula river (Policht-Latawiec, 2014).

Table 1

Coal output and saline mine waters discharge in years 2016 – 2021 (Environment 2016 – 2021)

Year	Coal output million tons/year	Saline water discharge thousand m^3/day	Approx. salt discharge tons/day	Utilization of saline waters million m^3/year
2016	70.4	308.7	3312	14.16
2017	65.5	342.8	3680	15.31
2018	63.4	361.6	3880	10.17
2019	61.6	344.4	3695	9.81
2020	54.4	343.7	3688	7.48
2021	55.0	356.0	3820	6.39

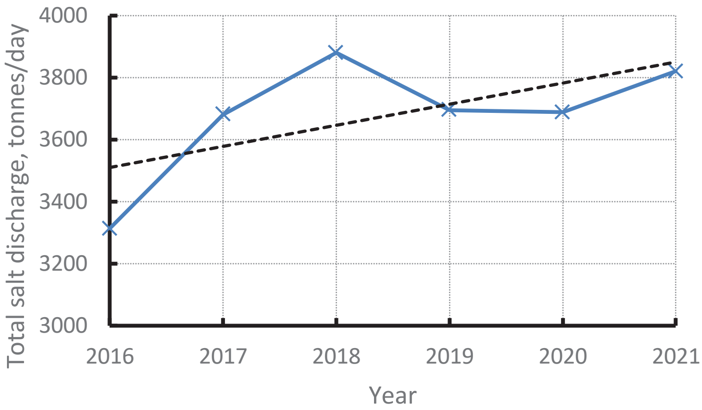

Figure 1 Total salt discharge into rivers in the period of 2016 – 2021 with linear trendline (on the basis of the data in Table 1)

Considering prospective balance of saline waters, deepening of mines must be considered in connection with vertical stratification of ground waters. In hydro-chemical conditions of USCB geological structures the zone of buried brines starts at the depth of 450 to 850 m (Różkowski and Różkowski, 2015). Large extents of the roof of this zone results from variability of geological conditions in each mine. From the other side, average depth of mining works decreases from about 300 m in 1957, through 650 m in 1989 (Różkowski and Różkowski, 2015). down to about 730 m in 2015.

3. CONTROLLED DISCHARGE OF SALINE MINE WATERS

In aim to avoid degradation of the ecosystems of watercourses, as well as to keep quality of water at obligatory standards, the most attention has been given to control concentration of Cl^- and SO_4^{2-} anions in watercourses instead of reduction of the salt stream discharged to the rivers.

Effective control of saline waters discharge requires an infrastructure that consists of pipeline connections between a group of mines and an adequately large retention reservoirs, which retain a stream of saline waters during low water level in destination watercourse and release them during high water level periods. In USCB exists two such a systems, which solve the problem of enormous concentration of salt in mine waters (where the sum of SO_4^{2-} and Cl^- exceed 42 g/dm^3. The “Olza Collector”, collects waters from eight coal mines, with a discharge rate of 30 thousand m^3/day, able to maintain the concentration of salts in Odra River below 0,5 g/dm^3 (Harat et. al., 2015; Swolkień & Filek, 2012).

Another one system has been created in aim to protect Vistula River against contamination by highly salinized waters and brines from mines “Piast” and “Ziemowit” (Strozik et. al., 2016). These mines, together with already closed mine “Czeczott” are responsible for 2/3 of total salts discharge from all USCB coal mines (Gruszczyńska et .al, 2014). The retention reservoir are created by voids being left in the rock mass after closure of mine “Czeczott”, in a volume of about 0,5 million m^3.

Controlled discharge of mine waters, especially from groups of coal mines, which generate majority of overall saline waters, makes them less intrusive for the environment of large watercourses, however it does not reduce the absolute mass of chlorides and sulphates being introduced into environment.

This article does not concern the issue of climate change, but in the context of the discharge of mine water into rivers, it should be emphasized that due to the increase in the salinity of the Odra River and the probability of golden algae blooms and other ecological disasters, in recent years, increasingly lower water levels in the main areas have been regularly recorded. rivers in Poland. This is illustrated in Fig. 2, which presents the values of the average annual water level at the Nowa Sól measurement point on the Odra River. Low water levels are accompanied by heat waves causing an increase in water temperatures in rivers, which, combined with the presence of significant concentrations of sulphates and chlorides from mine waters and other pollutants from various sources, causes a serious increase in environmental threats to the Odra and Vistula.

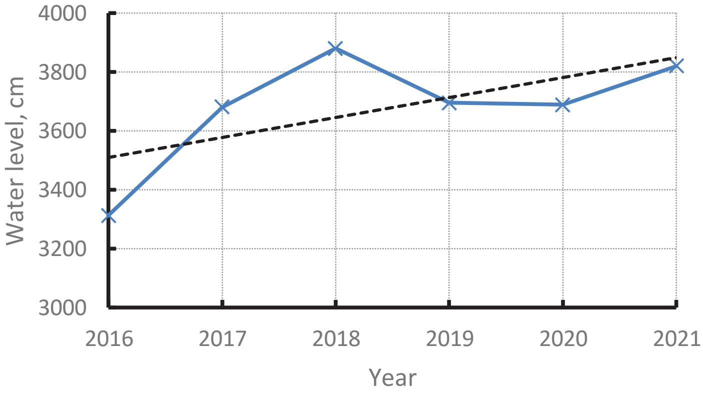

Figure 2 Average annual water level of Odra River at measuring point Nowa Sól with trendline (IOŚ-PIB, 2022)

4. CONTROLLED DISCHARGE OF SALINE MINE WATERS

In conditions of coal mining in USCB three ways of reduction of salt input into environment may be considered:

- Injection of saline waters into deep geological formations,
- Desalinization of mine waters,
- Use of mine waters for internal purposes of mines.

Saline waters from three mines undergo desalinization process in a plant of maximal capacity of 100 thousand t/year, which produces round 75000 t/year of salts (Andrusikiewicz and Tora, 2016). The plant reduces discharge of salt in to watercourses by nearly 6%. Technology adopted in the "Dębieńsko" desalinization plant is highly energy consuming. Production of one tone of salt requires almost 1 MWh of energy (Bobik and Labus, 2014). Experience collected from construction and operation of this facility unveiled a few serious obstacles against considering the desalinization as a general solution for mine waters problem. The main barriers are extremely high investment and operational costs of application of desalinization in desired extent and also, keeping in mind that total market of salt in Poland is about 2.1 Mt/year, covered mainly by salt mines, desalinization products from mine waters would create overproduction of NaCl and other products of round 1.3 Mt/year, fairly beyond consumption potential (Gruszczyńska et. al, 2014).

Another chance for significant reduction of saline waters discharge have been associated with brines and other highly salinized waters injection into deep absorptive geological strata. Potential of this method has not been yet scientifically sufficiently proved in conditions of USCB, however costs of its application would be probably highly much above economical acceptance, as show preliminary studies (Gromiec et. al., 2014; Gruszczyńska et. al, 2014).

The last option represents a group of methods, where utilization of saline waters occur inside a coal mine. Saline mine waters may be used as an own source of fresh waters, after desalinization in small scale plants (Bodzek and Konieczny, 2011). Such an installation implemented in a mine in northern part of USCB is producing round 60 thousand m^3/year of fresh water and 1300 tons of chlorides, sulphates, and other ions. The savings on fresh water delivery and environmental fees for discharge of saline waters are reaching more than 100 thousand euro/yr.

Use of saline waters in coal processing and underground air conditioning is insignificant, since such systems are operating in closed circuits. Relatively large area of mine activities, where water consumption is reaching substantial volumes is widely understood filling of mine voids.

5. TECHNOLOGY OF UNDERGROUND VOIDS FILLING

In 2022, a total number of 70 longwalls have been running in Polish coal mines, all of the with caving system. Number of longwalls with grouting of cavings is hardly to be identified, while frequently filling of voids (grouting) takes place temporary, only during increased probability of spontaneous coal ignition (endogenic fires) in longwalls, however, most of coal seams being currently extracted are prone to spontaneous ignition.

Filling of underground or voids occurs in variety of mining operations accompanying the main process of extraction of a mineral. Except descendent and rarely used technology of pneumatic placement of fill material, hydraulic transport is used to deliver fill materials and place them in the voids. Water may be used only as a carrier medium for hydraulic transport of solids or also as a compound, which interacts with the fill material. In most cases the fill material is expected to create a solid body after placement, so appropriate proportions of water to solids are required, to ensure best conditions for either hydration of cement and pozzolanic reactions, which are commonly used in binding of water-solids mixtures (Plewa et. Al., 2013).

From the point of view of maximized saline water utilization, only these underground technologies may be of interest, which consume regularly significant quantities of water. In this approach all occasional or small-scale backfill related operations, like liquidation of shafts or construction of backfill plugs remain out of scope of interest.

Reason for the use of backfilling is to keep the roof of a seam in relatively undisturbed conditions. Alternatively, in the system with caving, the roof rocks over a seam are supposed to collapse in a controlled manner. Rubble of fractured rocks is often called as gob area (Figure 3). While backfilling in underground coal mining is considered as inefficient for economic reasons, the only beneficial way of utilising saline waters is grouting of cavings in gob and voids of large dimensions. Considering differences between mining with backfill and grouting of cavings, one should noticed that in typical hydraulic backfill systems most of water is circulating in a closed circuit between backfill preparation plant, longwall panels, and drainage system of a mine (Palarski, 2013).

Grouting of cavings in a gob are behind a longwall front can be arranged in several ways, dependently on geometry of the seam and technical preferences related to space limitations, interference of grouting with other mining operations, available equipment etc. Most often, transport pipeline is located in the tail gate and grout is injected into cavings with use of short pipe outlets placed at the side of the gob area (Figure 3). In some variations of longwall systems, the tailgate is backfilled subsequently to advance of longwall. In such a case grout could be also used for filling of the tail gate. Another method requires location of the pipeline in the longwall, mounted on the face conveyor or hanging under the shields, with pipe outlets directed into the gob between the shields. Grout injections are especially effective in inclined coal seams, where elevation differences increase range of flow of slurries in voids (Palarski et. al., 2011).

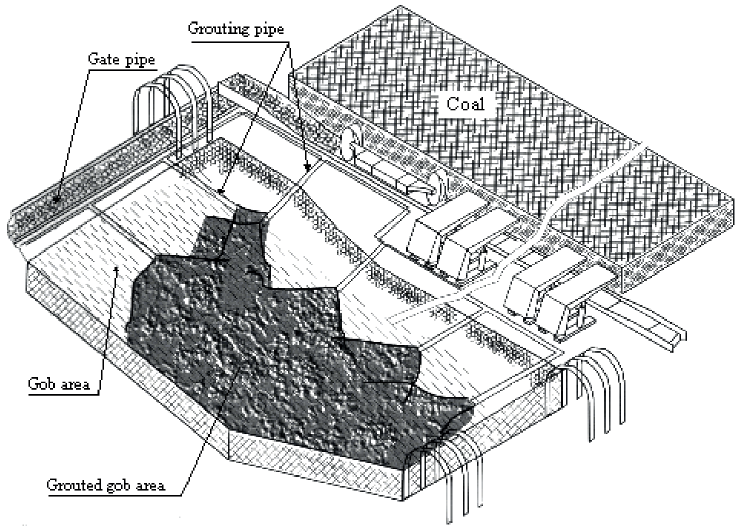

Figure 3 Schematic diagram of a longwall system with caving and grouting of the gob area (Palarski et. al., 2011)

5.1. REQUIREMENTS FOR GROUTING MIXTURES

Composition of a mixture has to meet the requirements for both pipeline flow and penetration in the gob area. Material for the grout must be also available in quantities adequate to volumes of voids, must meet environmental standards, and be able to create a solid body with mechanical properties expected by the conditions of application. Considering all factors, fly ash from hard coal combustion in power plants represents a raw material, which is able to meet all mentioned requirements. In general, the penetration of grout depends on many parameters such as composition of the slurry, applied grouting methods, pipe spacing, configuration of the roof fall rocks (porosity and surface roughness) and inclination of the footwall. The quality of the grouting mixture has an influence on the binding time, flow ability to migrate through caving fractures, sedimentation of the grout, amount of excessive and other. Binding time and sedimentation of a mixture for this technology should not be too short since the processes would cause a quick plugging of roof fall rocks. On the other hand an excessive amount of water, which cannot be absorbed neither by solidifying mix nor surrounding rocks would return to the drainage system. In similar way as in longwalls, old inaccessible cavings can by filled with mixtures containing large volumes of saline waters. If these abandoned parts of mine fields are isolated from the active mining areas, then is possible to maximize amount of saline waters in the mixture with resignation from their beneficial physical properties, within mentioned above limitations (Palarski et. al, 2011; Strozik, 2015).

5.2. INFLUENCE OF WATER SALINITY ON PROPERTIES OF GROUTING SLURRIES

When backfill operations are undertaken to reduce mine subsidence or improve the insulation properties of the rock mass, a maximized concentration of solids in the fill slurry is the target. When maximum deposition of saline waters has to be achieved by grouting operations, the composition of a fill mixture must be determined according minimal bleeding (excessive water presence) and the water absorptivity of the rock mass. The presence of chlorides and sulphates in water also influences the chemical processes of cement hydration and pozzolanic reactions of fly ash and binders with water.

Laboratory tests show that the presence of salt in water in a concentration up to about 60 g/dm^3 (as is the case for most mine waters from underground Polish coal mines) significantly increases the compressive strength of cured fly ash-water slurries and reduces their binding time, both in the presence of cement (Figure 8) or without an additional binder (Figure 6). Compressive strength and other properties of fly ash – water mixtures (binding time and table spread) have been measured accordingly to standard PN-G-11011:1996.

Figure 5 presents solidifying process of a typical fly ash – water mixture as a function of compressive strength. Presence of chloride and sulphate ions increases compressive strength of fly ash – water mixtures in relation to their percentage in water and cure time. Compressive strength, which can be considered as a factor of solidifying process, is growing far beyond the 28 days cure time and is still visible even after few months after placement in void (Plewa et. al., 2013). Faster development of compressive strength of fly ash – saline water mixtures is accompanying by retarded binding time (Figure 6), however the delay of start and end of binding between samples made with fresh water and mine water containing 60 mg/dm^3 of does not exceeds 1 ÷ 1.5 days (around 6 to 9% of a cure time.

Figures 78 and 8 present data from laboratory measurements of compressive strength and binding time of slurries intended to utilize brines. Fly ash from semi-dry desulphurization process and brines of concentrations 0.165 and 330 g/dm^3 have been mixed in solids to water ratio 2.4 ÷ 2.9 to obtain constant table spread of 180 mm.

The result show that after 28 days cure time, slurries containing sale in concentration 165 g/dm^3 exhibit twice higher compressive strength than mixtures with fresh water – Figure 8. Also addition of cement gives the mixture with brine of concentration 165 g/dm^3 more intensive dynamics of compressive strength development than mixture made with fresh waters.

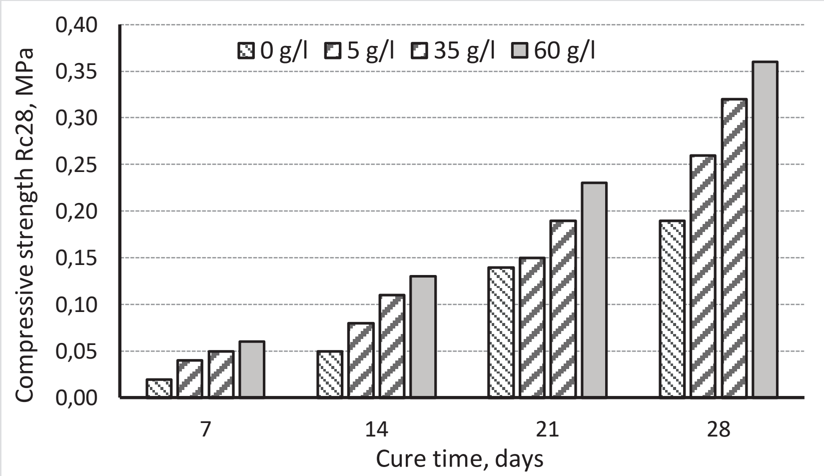

Figure 5 Compressive strength of fly ash-water slurries in relation to cure time and salinity of water; parameters of the slurry: solids to water ratio 1:1 slump 250 mm, fly ash from fluidal bed vessel

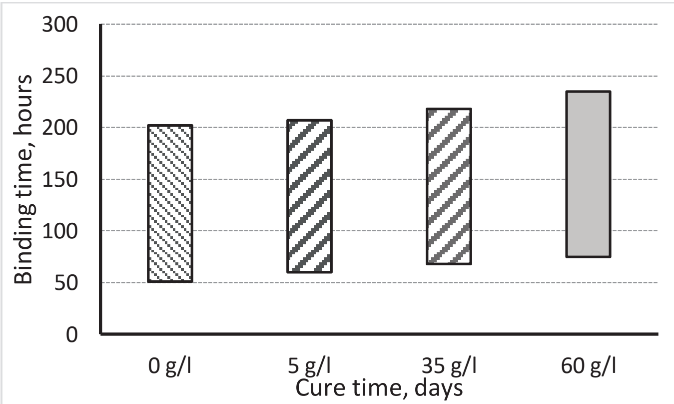

Figure 6 Binding time of fly ash-water slurries in relation to cure time and salinity of water, parameters of the slurry the same as in Figure 4

Beneficial relation between concentration of salt in water and growth of compressive strength is not linear and after exceeding certain value of concentration, the influence of salt in a mixture starts to be negatively affecting the compressive strength, down to values even below the parameters measured for mixture made with fresh water, as it is shown on Figure 7.

Figure 8 depicts influence of salinity of brines and percentage of cement, for the same slurries as presented in Figure 8 on binding time. It shows that any concentration of salt retards the binding process. By unfavourable conditions, binding time may be even infinite, it means that the slurry will demonstrate properties of viscous fluid rather than a solid body. In some specific conditions such slurries may generate risk of flooding of workings being in use. This risk is particularly pertaining slurries made with other than fly ash kind of industrial waste, like REA gypsums (originated from flue gas desulphurisation plants) or other finely grained waste or by-products, which do not exhibit binding properties without addition od of binders. However, addition of binders, mainly cement, increases significantly costs of filling of voids, so preferable are waste materials, which exhibit binding properties alone

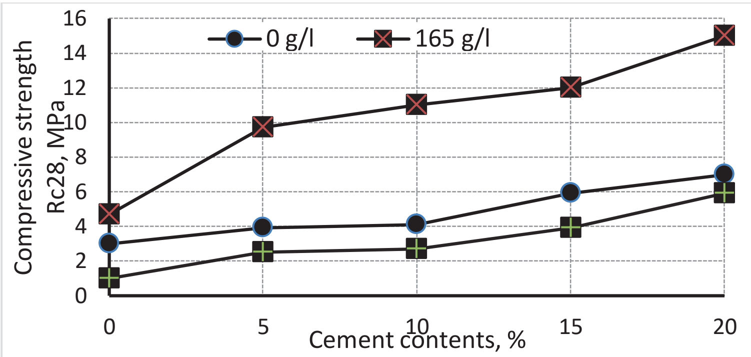

Figure 7 Compressive strength of fly ash – cement – brine slurries after 28 days cure time in relation to concentration of brine and percentage of cement (see text for details)

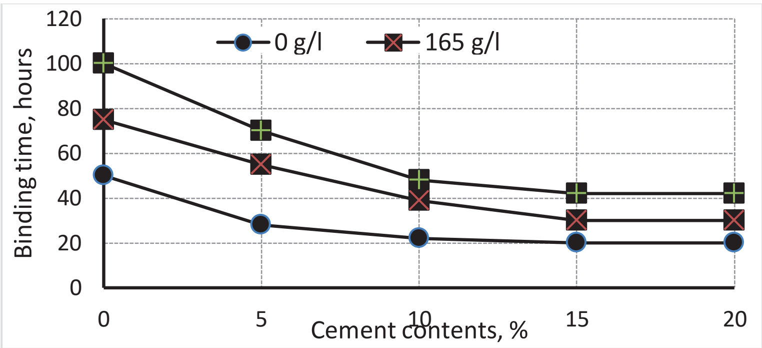

Figure 8 Binding of fly ash – cement – brine slurries after 28 days cure time in relation to concentration of brine and percentage of cement (see text for details)

6. ASSESSMENT OF POTENTIAL SCALE OF APPLICATION, ENVIRONMENTAL EFFECTS AND TECHNICAL ISSUES

The only critical factor for much more wider implementation of grouting of cavings is availability of fly ash. Consumption of fly ash by underground coal mining in Poland keeps in range between 2.35 and 2.60 Mt/yr during last decade, however with total production of fly ash on the level 45 Mt/yr, it makes about a half of it, which is utilized by coal mining industry (Palarski et. al, 2011).

A research on efficiency of filling of voids in cavings demonstrated that the coefficient of filling in longwalls (volume of grout being injected to expected absorptivity of cavings ratio) changes between 0.03 and 0.62 (Strozik, 2015). That means that even in longwalls where grouting voids was implemented, filling operations had been conducted occasionally

Considering output of coal as equal 55 Mt/yr the primal underground space of voids is round 40 million m^3/yr. Available space for filling is reduced by an empirically determined factor of 0.484 (Strozik, 2015), so the potentially available space for filling has a volume of 18.2 million m^3/yr. Even if a realistic coefficient of filling is only 0.154 (volume of slurry being injected to volume of available emptiness in longwalls determined on statistical data from industry), there is still 3 million m^3/yr voids to be filled. From the point of view of fly ash utilization, if the consumption of fly ash by coal mines is round 2.5 Mt/yr, then 2.5 million cubic meters of saline waters may be utilized by production of fill slurries.

In the environmental aspect, in first point should be noted that for preparation of fly ash – water slurries mines may use any waters they actually drain, so potential of this technique to utilize brines is frequently neglected. However, assuming that only 7% of total mine waters are brines, volume of mine waters, which should be eliminated from the environment at first place is round 8.3 million m^3. From this amount round 30% up to 48% could be utilized as a component of fill slurries in technology of grouting of cavings and filling of workings. Although the upper limit is only theoretical, utilization of about one third of total heavy salinized waters in technology discussed in this paper seems to be attractive and realistic solution. Utilization of brines in technology of filling of voids with fly ash - water mixtures is also economically valuable. Operational costs of filling of voids are low and fully justified due to its benefits: improvement of ventilation conditions, methane emission reduction, and endogenic fire prophylactics. Most of mines are equipped with mixture preparation plants and underground pipe distribution networks, if not – construction of a new preparation plant and piping does not implicate substantial investments. In some extent such an investment could be co-financed by environment protection sources. The only problem, which must be solved by implementation of discussed technology, is providing measures to collect and separate most salinized waters (brines) from the general stream of mine waters in drainage system of mines

7. CONCLUSION

It must be clearly understand that the general success of utilization of highly mineralized mine waters in fill slurries depends on wide application of the technology in all mines, in respect to the coal output of each mine. It would allow fully (or at least almost fully) accommodate highly salinized waters streams from scattered sources. Few mines, which generate the majority of salt input into environment, should use filling of voids in an extend adequate to their coal output, although controlled discharge into watercourses will be still the dominant way of their utilization.

Filling of mine voids with use fly ash – water slurries, where brines and highly salinized waters are to be utilized, is not expected to create opportunity for complete solution of saline waters input into environment. However, coal mines should take advantages from its application both in terms of mine hazards control and environment protection, and use it in as far as possible scale. In contrary to other methods of utilization of mine waters, this one does not generate significant costs, like it takes place in case of desalinisation.

Use of saline waters in technology of filling of mine voids belongs to highly appreciated category of waste management, described as use of waste at the source of origination, without any going into interference with environment.

From the point of the view of environmental risks for Odra river, just as there is no single cause of the catastrophic algae bloom in the Odra River, we cannot expect to find a single way to eliminate this threat. The management of mine waters and the reduction of discharges into rivers should take place wherever possible, and only the cumulative effect of many activities undertaken, even on a small scale, can bring visible improvement on the Odra River.

REFERENCES

1. Andrusikiewicz, W., Tora,B., 2016. Journal of the Polish Mineral Engineering Society 2, 135-141.
2. Bobik, M., Labus, K., 2014. Metody odsalania wód kopalnianych w praktyce przemysłowej – stan obecny technologii i nowe wyzwania 4, 99-105.
3. Bodzek, A.M., Konieczny, K., 2011. Usuwanie zanieczyszczeń ze środowiska wodnego metodami membranowymi, Wydawnictwo Seidel Przywecki Warszawa..
4. Bondaruk,J., Janson, E., Wysocka, M., Chałupnik, S., 2015. Journal of Sustainable Mining 14, 179-187.
5. Central Statistical Office, 2016. Environment 2017.
6. Central Statistical Office, 2017. Environment 2018.
7. Central Statistical Office, 2018. Environment 2019.
8. Central Statistical Office, 2019. Environment 2020.
9. Central Statistical Office, 2020. Environment 2021.
10. Central Statistical Office, 2021. Environment 2022.
11. Gromiec, M., Sadurski, A., Zalewski, M., Rowiński, P. Nauka 1, 99-122.
12. Gruszczyński, S., Motyka, J., Przegląd Górniczy 8, 142-149.
13. Harat, J., N. Rapantova, A. Grmela and Z. Adamczyk, Journal of Ecological Engineering 16(3) (2015) 61-69.

14. Instytut Ochrony Środowiska – Państwowy Instytut Badawczy (IOŚ-PIB), 2022. Raport kończący prace Zespołu ds. sytuacji w Odrze. Narodowy Fundusz Ochrony Środowiska, Warszawa.
15. Konsek, S., Czapnik A., 2020. Docelowy model odwadniania zlikwidowanych kopalń w Górnośląskim Zagłębiu Węglowym. Systemy Wspomagania w inżynierii produkcji 9(2), 99-110.
16. Molenda, T., 2014. Mine Water Environ. 3, 327-334.
17. Palarski, J., 2013. Environmentally Friendly Mining Technologies in Polish Coal Mining Industries. In: Proceedings of the 23rd World Mining Congress & Expo, Montreal, 11-15 August. Canadian Institute of Mining, Metallurgy and Petroleum (2013)
18. Palarski, J., Plewa, F., Strozik, G., 2011. Backfill and Grouting Technology in Underground Coal Mining Using Saline Mine Water. In: Ilgner,H. Ed. Proceedings of The 10th International Symposium on Mining with Backfill, Cape Town, 21-25 March, The Southern African Institute of Mining and Metallurgy, 15-20.
19. Policht-Latawiec, A., 2014. Acta Horticulturae et Regiotecturae 2, 4-47.
20. Plewa, F., Popczyk M., Pierzyna, P., 2013. Polityka Energetyczna (16)4, 257-270.
21. Swolkień J., Filek K., 2012. Wpływ zmian technologicznych w kolektorze „Olza” na skład chemiczny wód rezki Odry i jej dopływów. Rocznik Ochrony Środowiska 14, 945-959.
22. Matysik, M., 2018. Wpływ zrzutów wód kopalnianych na odpływ rzek Górnośląskiego Zagłębia Węglowego. Prace Naukowe Uniwersytetu Śląskiego w Katowicach nr 3651, Wydawnictwo Uniwersytetu Śląskiego, Katowice.
23. Różkowski, A., Różkowski, J., 2012. Impact of Saline Waters on River Water Quality in the Upper Silesian Coal Basin. Proceedings of The International Mine Water Association, 811-821.
24. Strozik, G., 2015. Wypełnianie pustek podziemnych w górotworze naruszonym eksploatacją górniczą. Wydawnictwo Pol. Śl. Gliwice.
25. Strozik, G., Jendruś, R., Manowska, A., Popczyk, M., 2016. Pol. J. Environ. Stud. (25)2, 777-785.
26. Zgórska, A., Trząski, L., Wiesner, M., 2016. Environmental Risk Caused by High Salinity Mine Water Discharge from Active And Closed Mines Located in The Upper Silesia Coal Basin (Poland). In: Drebensted, C., Paul M., Eds. Proceedings of The International Mine Water Association: Mining Meets Water – Conflicts and Solutions, 85-92.