Mine Waters from Ore and Coal Mining in Czech Republic

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Summary

Mine waters are quantitatively one of the most important products of mining activities and their negative impact on the environment may be extensive, even long after closing the deposit. The most important producers of mine waters in the Czech Republic are companies mining brown coal (Czech Coal a. s., Severočeské doly a. s. a Sokolovská uhelná, právní nástupce, a. s.) and black coal (OKD a. s.). Furthermore, mine waters are also generated in connection with mining of uranium ore (deposit Rožná) and a great amount comes from already abandoned ore and coal deposits under the control of the state enterprise DIAMO. Depending on the character of mine waters, treatment is required before their discharge into the surface waters. The paper also describes standard treatment technologies and other options of mine water desalination. In addition, the position of mine waters with regard to legislation is briefly summarized.

Keywords: mine waters, coal, ore, treatment

Introduction

The tradition of mining in Czech Republic has been long and notable. It is mainly associated with the extraction of Au, Ag and Fe at the times of Kelts' raids. A great boom in the metallic ore extraction occurred in the Middle Ages. Apart from Ag, a number of metallic ore deposits were mined, such as those of Au, Ni, Co, Pb, Mn, Fe, etc. Deposits of brown and black coal were of special importance. At present, only uranium is being extracted as for metallic ores, and coal is mined in a limited extent [1].

Mining of mineral resources impacts the environment markedly, even after its termination. Apart from the influence on the ground morphology and landcape shapes, the landscape's water regime is affected too. The exhausted mine space gets filled with water, namely due to precipitation, surface or ground water (Fig. 1) [1].

The extraction of mineral resources both in deep or surface mines greatly affects the water environment due to the fact that it often reaches below the ground water level. During mining activities water must be drained from the mined out areas. Next, water is used to reduce dust formation, in ore dressing, coal washing and hydrometallurgical extraction. For such purposes, water is supplied from surface water courses or ground water reservoirs, or it is obtained directly from mine drainage. Water gets into contact with rocks and it gets enriched with dissolved and suspended substances due to washing and mineral dissolution [1, 2].

In general, among all mine wastes and products arising in connection with mining and mineral processing, the quantitative abundances of mine waters are greatest [2].

Mine waters and their place in the legislation

The fundamentally binding legal regulation qualifying mine waters (MW) is Act 44/1988 Coll., on Protection and Use of Mineral Resources (Mining Act), wherein § 40 defines mine waters, their discharge, utilisation and discharge of other types of water into mine water.

What remains unqualified is the status of MW after mine closures, i.e. after the abandonment of a mine, quarry or a clay pit. No other provisions of the Mining Act refer directly to the issue of open flows of MW from abandoned mine workings after a mining company closure [4].

Mine waters and Water Act

For the purposes of Act 254/2001 Coll., on Water and amendments of certain laws (Water Act), as amended (amendatory act 150/2010, Coll.), mine waters are considered surface or ground waters, and if not stipulated by a special law, i.e. Mining Act in this case, they are regulated by Water Act. At the same time, it authorizes the water-right office to issue a decision on the determination of the method and conditions of mine water discharge into surface or ground water.

In determining such conditions, the water-right office follows the indicators of allowable pollution in water, stipulated in Government Decree 61/2003 Coll., as amended by 229/2007 Coll., in order to minimize possible pollution of surface water by discharged mine waters. The water-right office determines the limit values for MW discharge individually, according to local water conservancy conditions [4].

Mine waters and Atom Act

Discharge of MW containing radionuclides is permitted by the State Office for Nuclear Safety (SÚJB). Permissions are granted in accordance with Act 18/1997 Coll. on peace exploitation of nuclear energy and ion-radiation (Atom Act) and with amendments and complements to certain acts, determining reference values subject to Regulation 307/2002 Coll. on irradiation protection.

Classification of mine waters

Considering various mining activities, MW can be classified from a number of viewpoints, such as according to a source, mined raw material, or chemical composition. One of the basic MW classifications is according to the source. We distinguish natural and anthropogeneous sources of MW. Among the natural sources there are formation waters and other types of waters; among anthropogeneous sources there are process and service waters [5].

In the rock environment as well as in the conditions of mine wastes, there is a mutual interaction between the rocks (minerals), mineral processing products and water (Fig. 1. which MW gets enriched with various, frequently toxic elements.

The proportions of MW sources vary and it is not possible to define ‘typical mine water’ for the individual deposits. Within one mining company the types of MW vary also in time and space, they change along with the depth of winning operations, in dependence on the quality and composition of natural sources of MW in the given stage of mining, in active mines waters are polluted by operations and waste substances. Therefore, both the qualitative as well as quantitative data are only temporary [5].

From the point of view of chemical composition, the classification of mine waters is especially difficult. There are numerous schemes of classification based on one or several parameters of MW, e.g. based on major cations and anions. Next, MW can be classified on the basis of the pH value [7], the pH value and concentration of Fe^{2+} and Fe^{3+}, the pH value and total dissolved metal content, etc. [8]. A special category of MW is represented by Acid Mine Drainage (AMD). AMD is charac-

Fig. 1. Hereditary adit Kaspar Pflug, Horní Slavkov

Rys. 1. Sztolnia Kaspar Pflug, Horní Slavkov

Fig. 2. Hereditery adit in Příbram

Rys. 2. Sztolnia w Przybramiu

teristic of low pH (<5.5) [7], while a significant source of H^+ ions is the oxidation of pyrite (FeS_2) and other sulphidic minerals. During the oxidation of sulphide, free sulphuric acid is formed and metals and sulphates are released into water, which accelerates leaching of other elements from ore-bearing rocks. This means that AMD is associated with the release of sulphates, heavy metals (Fe, Cu, Pb, Zn, Cd, Co, Cr, Ni, Hg), semi-metals (As, Sb) and other elements (Al, Mn, Si, Ca, Na, K, Mg, Ba, F). In general, AMD from coal mines contains much lower concentrations of heavy metals and semi-metals than drainage from deposits of basic metals or gold [9].

Mine water treatment

In general, mine water treatment methods may be divided into active and passive one [1, 2]. Active methods require continuous addition of reagents, active maintenance and monitoring, and they need mechanic devices for mixing reagents and MW. On the other hand, passive methods make use the natural water flow and chemical and biological processes to increase the pH value and to lower the concentrations of dissolved metals; they take place in wetlands, bioreactors, or oxic and anoxic limestone beds.

Active methods of mine water treatment work on the principle of increasing the pH value and induction of oxidizing-reducing conditions. Among the major procedures there is reduction of acidity by alkalis (e.g. $Ca(OH)_2$, $CaCO_3$, $NaHCO_3$). Having added alkalis, along with a rise in alkalinity there is a drop in metal solubility, which begins to precipitate into the form of oxides and hydroxides from the solution and may be separated in sludge. The disadvantage lies in high consumption of expensive chemicals, the costs of system operation and maintenance and the issue of storing and disposal of formed sludge that often includes toxic elements [2].

Alternative active mine water treatment methods. These are, for example, processes making use biological methods, the so-called bio-desalination. This process makes use of joint treatment of MW and sewage water, during which bacterial reduction of sulphates occurs [1]. Next, it is possible to employ the processes of sorption, ion exchange, extraction, percolating biofilters, etc. Apart from the capture of contaminant metals, those methods may be also used for other purposes.

One of the modern membrane MW treatment methods is electrodialysis (ED) working on the principle of element capture based on their electric charge. This method has been used by workers of VŠB-TU Ostrava in desalination of MW from black coal deposits in Ostrava-Karviná Coal District (OKR), Czech Republic, within a joint project MPO TIP "Research and testing of modern technologies on the base of membrane processes to demineralize and utilize mine waters in OKR". The proposal of a complex technology of pre-treatment and processing of MW by means of membrane processes was verified in a practical pilot regime in a water catch pit VJ Jeremenko. On a station scale, the proposed technology was prepared for the processing capacity of 120 $m^3.h^{-1}$. To desalinate pre-treated MW to reach concentrations of 1g. l^{-1} by means of ED, four ED cell units were used. The evaluation of the obtained data points at a high application potential of membrane technologies in the conditions of desalination of mineralized MW from OKR black coal deposits. Currently, the MW is conducted into surface streams, which strains the environment by increased concentrations of dissolved salts in the waters in question [10].

Mine water treatment using fly ash. The application of coal fly ash as a neutralization agent in MW treatment has been the subject of numerous studies. They observed various parameters, e.g. solubility of mineral phases from fly ash and their reaction with metals in MW, their significant influence and subsequent impact on the solubility of newly formed mineral phases [11]. Mine water treatment by synthetic zeolites, prepared from coal fly ash, particularly in metal removal has proved similarly efficient [12].

Passive mine water treatment methods are grounded in the support and exploitation of natural biogeochemical processes. Their great advantage is minimum costs. It is possible to divide them into aerobic remediation systems (aerobic wetlands – presence of O_2) and anaerobic remediation systems (anaerobic wetlands – no O_2) [1, 2].

Mine waters from mining of coal and ores in Czech Republic

Mine waters from black coal mining

In the CR the only producer of black coal is the company of OKD, a. s., which extracts coal in the underground mines of the Ostrava-Karviná Coal District, in the southern part of the Upper-Silesian Coal Basin. Mine water is drawn from the mines of ČSM, Karviná, Darkov and Paskov. The drawn MW is slightly alkaline sodium of a chloride type. Therefore, it is especially characteristic for a high content of chlorides ranging in concentrations of up to 103 $mg.l^{-1}$. Next, the water is observed for

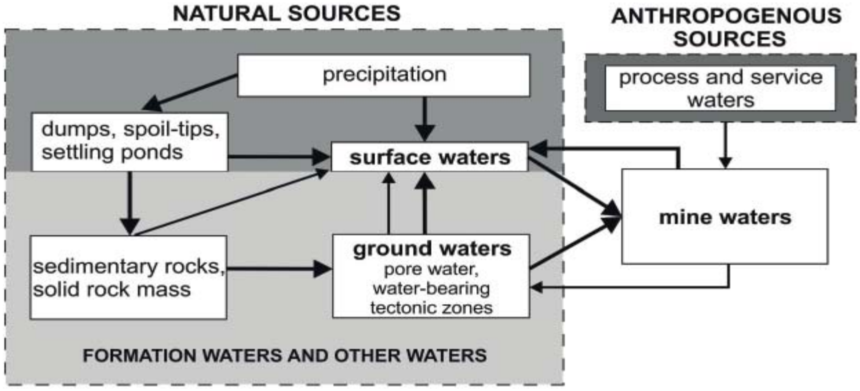

Fig. 3. Diagram of interactions among deposit rocks and waters that influence the quality of ground and surface waters within a deposit [6]

Rys. 3. Diagram interakcji pomiędzy złożem skał a wodami mającymi wpływ na jakość ziemi i wód powierzchniowych w obrębie złoża [6]

the concentrations of sulphates, Fe, Mn and suspended solids. Based on relevant regulations, MW is discharged into streams. For safety reasons, water is pumped also from the closed or abandoned mines, namely due to securing a stable MW level which shall not endanger mining activities in the active part. The localities are administered by a state enterprise DIAMO (odštěpný závod ODRA), and namely they are the water catch pits Jeremenko and Žofie. The character of the MW is similar to MW drawn from active mines.

As for the volumes of MW, based on the documents (obtained from OKD, a. s. a DIAMO, s. p. on MW volumes discharged into the streams in the locality) in 2011 the total discharged volume was 12 million m^3. The water is discharged into the Karvinský stream, or the Orlovská gutter and the Ostravice River. Such water may also be used in therapeutic application, such as in the spas of Darkov and Klimkovice. In the past, such water was used to produce the so-called healing Darkov salt. The state enterprise DIAMO also runs a mine water treatment station (MWTS) in Oslavany, through which the treated MW from the Rosice-Oslavany Basin is discharged in the volumes of about 1.6 million m^3 a year.

Mine waters from brown coal mining

Brown coal is an important resource for the generation of power and heat in the CR. In the North-Bohemian Brown Coal Basin the leading mining companies are the holding of Czech Coal a. s. and Severočeské doly a.s., and in the Sokolov Basin it is the company Sokolovská uhelná, právní nástupce, a.s. Mine water from brown coal mining is characteristic for low pH, high concentration of sulphates, increased concentrations of Fe, Mn, Al, Mg and Ca. All the above mentioned mining companies operate mine water treatment stations. The mining companies of Vršanská uhelná a.s. and Litvínovská uhelná a.s. (members of the holding Czech Coal, a.s.) treat mine water in two mine water treatment stations of giant opencats ČSA – JŠ and Vršany. The treated water is discharged into the receiving body of the Bílina River and Slatinický stream. The company of Severočeské doly, a.s. also runs two mine water treatment stations, namely Emerán and Březno. The treated water is discharged into the watercourse of Hutná and the Břežánecký stream. Sokolovská uhelná, právní nástupce, a.s. treats MW in Svatava MWTS and discharges it into the Svatava River.

In principle, the technology of all treatment stations is analogous and lies in the alkalization by means of limewash, oxidation by means of aerators which is in certain stations complemented by dosing potassium permanganate (i.e. in ČSA-JŠ, Březno, Emerán) and final thickening of the sludge by means of a flocculant. Adding up the MW volumes from the individual localities, in 2012 the overall volume of discharged water from such MW treatment stations was 14 million m^3.

Mine waters from ore mining

At present, in Czech Republic deep uranium mining is executed only within Rožná Deposit. Apart from this, remediation of an exogenous deposit Stráž pod Ralskem is under way, from where uranium is recovered from pumped uranium-bearing solution (originally there was a chemical extraction of U from Cenomanian sandstone) [6]. In other localities with terminated ore extraction the state enterprise DIAMO operates mine water treatment stations (MWTS) or monitors the quality and quantity of mine drainage. In total, in 2012 about 7 million m^3 of MW were discharged from

31 outlets. The quantity of discharged waters depends especially on precipitation and its character in the given year and local hydrogeological conditions. It may be stated that the composition of such MW mostly meets the discharge limits for discharge canals and that it need not be further treated. Moreover, some of the mine waters have such properties which make them applicable as drinking, service or mineral waters (e.g. the localities of Řídeč and Kraslice) and in balneotheraphy (Jáchymov). On the other hand, there are localities where it is necessary to apply technological procedures for MW treatment in order to avoid environmental damage before its discharge. The state enterprise DIAMO currently runs 21 MWTSs. The basic technology usually lies in the modification of pH and metal precipitation through dosing limewash. Such treatment stations are operated, for example, in Zlaté Hory, Kutná Hora or Běstvina.

A more complex technology is used in MWTSs within uranium deposits. Such MWTSs are currently in operation, for example, in uranium deposits in Stráž pod Ralskem, Příbram, Okrouhlá Radouň, Horní Slavkov, Olší, Licoměřice, Pucov and Rožná (active mining). Mine water treatment stations are usually constructed as modular systems with individual technological units downstreamed in lines which may be incorporated independently, in series or parallely in order to reach as best quality of the discharged water as possible in dependence on the MW quantity at the MWTS feed. The following technological operations or their combinations are typically used, namely aeration with subsequent sedimentation; dosing of $BaCl_2$ to eliminate radium, or supplying of sulphate ions; single or double-stage modification of pH, or potential dosing of flocculants and subsequent sedimentation; filtration in pressure sand filters; separation of residual uranium in ion-exchangers; in certain specific cases (e.g. chemical treatment station for uranium ore in Rožná) an evaporating station, dialysis and a reverse osmosis line [6].

Removal of sulphates from mine water

Mine waters, especially related to brown coal mining, contain higher concentrations of sulphates. To remove SO_4^{2-} ions there are a number of procedures, each with its advantages and drawbacks. All the processes leading to lower concentrations of SO_4^{2-}ions below 300 mg.l^{-1} (maximum admissible concentration of sulphate ions in surface water) would require upgrading the existing technologies operated in MWTSs. For example, barium ions precipitation is efficient but brings along certain toxicological risks, especially in the case of overdosing barium salts in the precipitation process. In addition, it is necessary to take the issue of sludge disposal into consideration. There is also aluminium ion precipitation into ettringite (hydrated aluminium ammonium sulphate), which is a technology requiring final modification of pH values as sulphate precipitation to ettringite occurs in strongly alkaline levels. Another process is the ion exchange which is grounded in the application of strongly acidic cation exchanger, where cation exchange from the aqueous medium for hydrogen ions occurs, followed by weakly basic anion exchanger, where anions (particularly SO_4^{2-}) are exchanged for hydroxide ions. This technology represents an incorporation of another technological step, including regeneration of cation exchangers and anion exchangers. Another option is an incorporation of membrane processes, i.e. reverse osmosis, electrodialysis, and ultrafiltration. In the case of membrane processes and ion exchange it is very important to pre-treat water, which is to ensure the removal of coloids and suspended solids. The objective of pre-treatment is the prevention of the formation of precipitates in the facilities and on the membranes. Applying the membrane technology and ion exchange, it is vital to ensure the disposal of regeneration solutions and the relevant concentrates. All the mentioned processes represent significantly higher costs of treatment when compared with the existing technologies and operations.

Conclusion

Mine waters and their disposal are inseparably related to the industrially exploited landscape. In developed countries, mining companies are obliged to minimize the effects of discharged mine waters on the environment. In Czech Republic this requirement is met and mine water is treated in wastewater treatment stations.

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Wody kopalniane z rudy i kopalni węgla w Czechach

Wody kopalniane są ilościowo jednym z najważaniejszych produktów działalności kopalni i ich negatywny wpływ na środowisko może być rozległy, nawet na długo po zamknięciu złoża. Najwięcej wody kopalnianej w Czechach produkuje się w firmach wydobywających węgiel brunatny (Czech Coal a.s., Severočeskédoly a. s. a Sokolovskáuhelná, právnínástupce, a. s.) i węgiel kamienny (OKD a. s.). Ponadto, wody kopalniane tworzą się również przy kopalniach rudy uranu (złoże Rožná) i spora jej ilość pochodzi już z opuszczonego złoża oraz złóż węgla będących pod kontrolą przedsiębiorstwa państwowego DIAMO. W zależności od właściwości wód kopalnianych, wymaga się ich oczyszczenia przed wypuszczeniem do wód powierzchniowych. Praca opisuje również standardowe technologie i inne opcje odsalania wody. Dodatkowo, w skrócie podsumowane zostają pozycje wód kopalnianych w relacji do rozporządzeń prawnych.

Słowa kluczowe: wody kopalniane, węgiel, ruda, obróbka