ECONOMIC PROBLEMS RELATED WITH THE ELIMINATION OF THE ADVERSE EFFECT OF MINING BY STOWING THE UNDERGROUND SPACE

EKONOMICKÁ PROBLEMATIKA ŘEŠENÍ NEGATIVNÍCH VLIVŮ HORNICTVÍ FORMOU ZAKLÁDÁNÍ PODZEMNÍCH PROSTOR

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Abstract

The contribution deals with the stowing of the underground space in underground coal mines. It used to be a part of the mining technology and has also been used as a means of the underground mines liquidation in the Czech Republic. The case of Jan Šverma Mine is described, the liquidation of which has been carried out by stowing all the underground space with a stowing mixture made of industrial waste. The payments received for the withdrawal of industrial waste for the purpose of treatment have covered most of the liquidation costs. This proves that the use of stowing in the mining industry is economically feasible. Thus, negative impacts of mining on the environment can be mitigated.

Abstrakt

Příspěvek se zabývá zakládáním podzemních prostor hlubinných uhelných dolů, které bylo v České republice použito jako součást technologie dobývání i jako způsob likvidace hlubinných dolů. Je uveden příklad Dolu Jan Šverma, který byl likvidován založením všech prostor základkovou směsí vyrobenou z průmyslových odpadů. Platby za odběr průmyslových odpadů ke zpracování pokryly většinu nákladů spojených s tímto způsobem likvidace. Prokázala se tak ekonomická proveditelnost použití zakládání v hornictví. Tímto způsobem lze omezit negativní dopady hornictví na životní prostředí.

Key words: stowing, underground coal mines, underground mines liquidation, liquidation costs.

1 INTRODUCTION

The prevailing negative attitude of the public towards the mining industry stems from the impact of underground extraction on the environment. The damage to the environment and property of persons and institutions occurs not only during coal-getting operations, but also after they have discontinued. Abandoned and improperly secured mines become the sources of health and safety risks. The common cause of the negative impact of underground mines is the disturbing of the rock mass and the formation of underground space. Over time, the underground space partly collapses impairing the stability of the ground and resulting in migration routes for damps and groundwater.

The mining industry has responded to the negative attitude of the public by approaching mining as the temporary deprivation of land. After the termination of mining operations the original condition or another desired condition of the land is supposed to be restored. The restoration can commence during the mining operations as well as after their termination. In both the cases it involves the stowing of underground space, which reduces the negative impacts of underground extraction on the surface and enables a faultless technical liquidation of closed mines.

Under the conditions of underground coal mining in the Czech Republic, stowing used to be a part of the mining technology. Occasionally, it has been used as a means of technical liquidation of the entire underground mine. A general problem with both the cases is the high cost of the procedures. Stowing as a part of the mining technology was gradually abandoned in the past. For economic reasons, too, filling of the principal mine workings with surface entrances was preferred in the case of technical liquidation of underground mines.

However, the use of industrial waste for the production of stowing mixtures has brought new possibilities. The solution of the economic part is based on the assumption that the producer of industrial waste pays for its disposal, which, in most cases, means its dumping on waste dumps. Industrial waste can be withdrawn by the company, which will use it for the production of stowing mixtures and which is then entitled to the payment from the waste producer. Thus, the expenses related to the production of stowing mixtures and the cost of their stowing underground are covered.

Under the conditions of the Czech Republic, one underground mine has been liquidated using the method discussed. [1] Generally, it has proved to be the solution to the safety and environmental issues related to underground space that can be carried out with acceptable economic results.

2 NEGATIVE IMPACTS OF UNDERGROUND COAL MINING

The negative impacts of underground coal mining can be divided into impacts incurred during mining operations and impacts incurred after the termination of mining operations.

2.1 Negative impacts incurred during mining operations

Coal mining underground brings about a substantial intervention in the rock mass leading to the development of induced stress and deformation fields. During coal extraction materials are displaced from their original location before human intervention and new conditions on the surface are created. Atmospheric action causes weathering processes, which may even be accompanied by spontaneous oxidation of coal matter in the waste rock – burning of mine dumps. Therefore, the surface environment is affected in many ways. The most significant negative effects are [2]:

- Deformation of the surface: one of the consequences of coal extraction is the occurrence of surface subsidence and in critical cases even sinking, which affects the morphology of the landscape on the surface. In residential areas it has adverse effects on surface buildings.
- Mine dumps: the technology of depositing the waste rock has undergone some development over time. The oldest preserved small mine dumps were piled up nearby adit collars. With the development of underground mining the poured conical mine dumps emerged. Later, flat or terraced mine dumps were purposely created for a specific use. However, mine dumps with advanced oxidation of dispersed coal matter, i.e. burning mine dumps, may become hazardous.
- Effects of undermining on the outflow conditions: the fundamental issue of undermined water streams is the gradient condition. The upright faults cause a deformation in the length-profile and lead to changes in the runoff regimen in the affected sections. The formation of a subsidence trough results not only in an increased erosional activity in the length profile, but also in the reduction in the gradient accompanied by inundation of the adjacent areas.
- Impact of undermining on water areas: underground mining creates a number of areas without the outflow, which brings about continuous flooding in subsidence basins. The flooded areas are often reclaimed by filling with waste rock or occasionally, they become slurry ponds or mine dumps.

2.2 Negative impacts incurred after the termination of mining operations

The effects of coal-getting operations on the surface are felt many years after the extraction has been terminated and thus, all the effects discussed in the previous chapter continue to be at work even after the termination of coal extraction.

However, the major risk that the period encounters is posed by damps. After the termination of coal extraction and technical closure of a mine, the drainage of gas rich in methane by mine air as well as the controlled degassation of coal seams discontinue. Gradual inundation of the coal mine follows. The gas cumulates in the cavities of mine workings and the loosened rock mass in the roof of mine workings, and mixes with coal bed methane released from the disturbed pillars and unworked parts of coal seams. Within a few years of mine closure, gradual degassing of the rock mass takes place with the gas exhaling to the surface.

The presence of natural and man-made contact channels enables the penetration of damps from non-inundated parts of closed mines in the Carboniferous massif through the cover into the soil air and subsequently into the atmosphere and/or the underground and surface facilities. A significant factor in the gas migration is the existence of old mine workings that have not been closed – shafts with surface entrances or long mine workings situated at a shallow underground depth. Other factors influencing the methane emission to the surface are climatic and atmospheric conditions.

The emission of mine gas to the surface produces suffocating mixtures in bounded space and these are liable to explosion or fire even in the open. Coal mining industry in the Czech Republic has seen such cases that had fatal consequences.

3 ELIMINATION OF THE ADVERSE EFFECTS OF MINING BY STOWING THE UNDERGROUND SPACE

Negative impacts of mining during coal-getting operations or after their termination ale linked with the creation of underground space. In theory, the issue can be solved using a reverse procedure – the filling of the abandoned underground space in order to prevent the deformation of the surface and to close the contact channels for gas and water. In the past the method used to be a part of the mining technology while lately it has been applied as a means of the liquidation of mines.

3.1 Stowing as a part of the mining technology

The stowing of the worked-out space was prompted by the following reasons [3]:

- Protection of the above ground and mine buildings and facilities situated above the exploited deposit, as the roof layers may sag, but will not sink.
- Regulation of the pressure in workings with the pressure effects in drifts being attenuated.
- Favourable conditions for ventilation and safety of the mine, as there is no leakage of air or formation of open space in which damps or water would cumulate.
- Stowing enables bench mining of very high coal seams.
- Stowing of waste rock in workings reduces its transport to the surface and its depositing in mine dumps.

The materials used for stowing were primarily waste rock, waste coal, sand, gravel, and other materials including cement or plaster, which caused the solidification of the stowing mixture.

When compared to the induced caving of the worked-out space, the stowing method had some disadvantages:

- Higher costs: capital costs are incurred on the purchase of machinery and equipment for the treatment of the stowing material, transport and the actual stowing of the worked-out space. The transport, treatment and stowing incur operating costs; the number of the shifts worked increases thus increasing the labour cost.
- The mining method of stowage type is more complicated from the organizational point of view than the induced caving.

As a result of the above reasons, the application of stowing began to decline until it was abandoned completely. The development in the largest coalfield with underground coal mining, Ostrava- Karviná Coalfield, is shown in Table 1. [4]

Tab. 1 The percentage of stowed area in the total worked-out space

year	1960	1965	1970	1975	1980	1985	1990	1995	1997
percentage	20.8	16.3	13.7	8.5	9.6	7.9	8.5	0.9	0.4

It is rather paradoxical that since 1990 coal mining has been restricted to mines with high coal seams, which have even more profound impact on the surface buildings and the environment.

3.2 Stowing as a part of the technical liquidation

In the Czech Republic, technical liquidation of underground mines has been executed by means of inundation, hydraulic stowing, backfilling of the shafts with loose material, or a combination of the methods. In all the cases the surface entrance to the shaft is sealed with the concrete bulkhead.

A unique method used for the liquidation of an ore mine has been backfilling of the worked-out space, tectonic structures and mine workings with concrete at a total volume of 12,339 m^3. The backfilling was carried out between March 1992 and November 1993 and the monitoring performed ever since has shown no impact of the exploitation on the surface. [5] However, the mine in question was very small with merely a 55-meter deep shaft. The project was financed from the state budget and the cost exceeded USD 1 million at the current exchange rate. For a private mining company the method would not be economically feasible.

Another example of a unique liquidation of an underground coal mine has been a private liquidation of Jan Šverma Mine in the town of Žacléř in eastern Bohemia. It was carried out by means of stowing the principal mine workings as well as all the underground space with a stowing mixture made of industrial waste. [6]

At the time the decision on the liquidation was taken, Jan Šverma Mine consisted of 65 km of up to 941-meter deep mine workings on nine levels. The stowing of underground space commenced in 1993; at present the underground space between the first level and the surface is being liquidated. The filling of all the horizontal, vertical, and sloping mine workings produced the following results:

- Prevention of the discharge of mine water, which would otherwise have to be decontaminated before its discharge into surface water streams.
- Prevention of the emission of mine gas to the active parts of the mine.
- Prevention of endogenous fires.
- Prevention of the emission of mine gas to the surface.
- Prevention of surface deformation as a result of induced caving of abandoned mine workings.

Another unique feature of this liquidation project is the financing of the operations.

4 USING INDUSTRIAL WASTE TO PRODUCE STOWING MIXTURES

4.1 Technical solution

In the past, hydraulic stowing mixtures used in underground coal mines were mostly made of flotation waste rock and heating or power plant ash and slag. Occasionally, cement was added to increase the strength of the mixture. Thus, the hydraulic stowing mixture was a special type of concrete mixture.

Research and experience have extended the range of input components of stowing mixtures by various kinds of waste from iron metallurgy, coal mining, and coal combustion as well as the waste generated by cement industry, stone processing and some other types of industrial waste. These types of waste are normally deposited on waste dumps; the waste producer has to pay for the disposal.

The possible solution to economic problems related to the stowing of underground space, notably in the case of the liquidation of mines, is based on this very assumption.

4.2 Stowing economy

From the economic point of view, technical liquidation of a mine is a loss-making activity, for the execution of which a reserve fund has to be created during the active period of the mine. The sources yielded after the extraction has been terminated will be very limited – e.g. sale of machinery and material from the mine to be liquidated. The liquidation of the above-mentioned Jan Šverma Mine began at the time when the Mining Act did not prescribe the creation of the reserve in question. Therefore, Gemec, a.s., a joint-stock company in charge of the liquidation of the mine, received a state subsidy covering the cost of energy and wages incurred on the liquidation. The state subsidies were granted between 1993 and 1996. From 1997 onwards the liquidation of the mine was financed from the money received from waste producers for the withdrawal of industrial waste. Under the circumstances, the basic factors influencing the stowing economy are (i) the price paid for the withdrawal of industrial waste for the purpose of processing (ii) the quantity of industrial waste processed (iii) the variable cost of waste processing and depositing of stowing mixtures (iv) the shut-down cost of the liquidated mine. In theory, the savings incurred by the liquidation of a mine by stowing (e.g. the mitigation of mine damage) might be taken into account, but practice has disproved the importance of this item.

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4.2.1 The price paid for the withdrawal of industrial waste for the purpose of processing

The stowing mixture is made of various kinds of industrial waste at a proportion determined by research. The price paid for the withdrawal of industrial waste has to be lower than the price paid for its depositing on waste dumps. According to statistical data, other types of waste are withdrawn for approximately 70 per cent of the “waste dump prices”; hazardous waste is withdrawn for 1 third of the price paid for its depositing on waste dumps. The comparison has shown that there is a scope for the increase in the price paid for the withdrawal of industrial waste for the purpose of processing. Moreover, under the Waste Act the charges for the depositing of industrial waste on waste dumps will increase as well. It will therefore be possible to raise the prices for the withdrawal of industrial waste for the purpose of processing and by doing so, to improve the stowing economy.

4.2.2 The quantity of industrial waste processed

The quantity of industrial waste withdrawn from its producers for the purpose of processing has a double influence: its growth increases the revenues from the withdrawal of industrial waste and reduces the portion of the fixed cost of the technological line per unit of the stowing mixture produced. Therefore, the waste treating company should seek to maximize the waste withdrawal as well as the production and use of the stowing mixture. The volume in question is determined not only by the size of the underground space available for stowing and the capacity of the technological line for the production of the stowing mixture, but also by the ability to procure industrial waste from its producers. It can be demonstrated on the fluctuation in the yearly volumes of the stowing mixtures produced and used for the liquidation of Jan Šverma Mine. [1]

Tab. 2 The yearly quantity of stowing mixtures produced

year	1993	1994	1995	1996	1997	1998	1999
tonnes	20,020	67,349	90,274	56,650	12,847	61,750	26,828

year	2000	2001	2002	2003	2004	2005	2006	2007
tonnes	36,289	66,316	57,603	58,364	22,693	25,545	21,682	19,570

The 1997 drop in the quantity of waste withdrawn and stowing mixtures produced posed severe economic problems to the company.

4.2.3 Variable cost of waste processing and the depositing of stowing mixtures

The variable cost of the production of stowing mixtures and their depositing underground is considered to be the cost of transportation and handling of industrial waste. Other cost items (e.g. energy and wages) are of a mixed nature with prevailing fixed item, whose precise determination is complicated. The variable cost is influenced by the availability of the sources of industrial waste and by its quantity. This may be demonstrated on the ratio of the highest to the lowest variable unit cost, which, for the liquidation of Jan Šverma Mine, was 6.9.

4.2.4 Shut-down cost of the liquidated mine

The shut-down cost of mine operation is described as the cost of ensuring the necessary operation of the facilities in the mine and on the surface of the liquidated site. It further includes the cost of liquidation management activities. The cost exists as a result of the fact that all the security systems of the underground mine have to be kept operating until the liquidation of the principal mine workings is completed. The shut-down cost is influenced by natural, technical and technological conditions, which are unique to each mine. Therefore, it can be considered an external factor, whose amount is the determinant of the profit or loss of the whole process of industrial waste processing and the depositing of stowing mixtures underground.

The discussed Jan Šverma Mine has been liquidated by means of stowing all the underground space with a stowing mixture made of industrial waste. Major portion of the cost has been covered by the amounts received for the withdrawal of waste from waste producers. A part of the income has come from the sale of repaired mine support. The stowing economy has been improved by the following measures:

- Use of new stowing mixtures made of industrial waste with higher withdrawal prices.
- Making use of the rise in the charges paid for the depositing of industrial waste on waste dumps.

• Making use of the gradual reduction in the shut-down cost as the liquidation of the underground mine proceeded (reduced ventilation and pumping of mine water etc.).

5 CONCLUSIONS

The liquidation of Jan Šverma Mine has shown in practice that the stowing of all the underground space eliminates safety and environmental risks inherent to closed mines. Moreover, a problem of more than 640,000 tonnes of industrial waste, which otherwise would have been deposited on waste dumps, has been permanently solved. In a long-term perspective, waste dumps pose a threat to the environment.

Of special importance is the finding that the amounts received for the withdrawal of industrial waste can cover most of the costs related to the liquidation of a mine by stowing. The example discussed shows that industrial waste can also be used for the stowing of worked-out space as a part of the mining technology. In this case, the shut-down cost is not incurred and so it can be assumed that from the economic point of view, it not a loss-making activity.

The replacing of natural materials with a mixture made of industrial waste for the stowing of underground space substantially mitigates or even completely eliminates the adverse effects of mining on the environment. Thus, the attitude of the public towards the mining industry can be improved and a compromise between the requirements for the mining industry activities and the protection of the environment can be achieved.

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RESUMÉ

Negativní dopady hornické činnosti v průběhu těžební činnosti nebo po jejím ukončení jsou spojeny s vytvářením podzemních prostor. Teoreticky lze tyto problémy řešit opačným postupem – zaplněním volných podzemních prostor pro zamezení deformací povrchu a uzavření komunikačních cest pro plyn a vodu.

V podmínkách hlubinného uhelného hornictví současné České republiky bylo zakládání používáno jako součást technologie těžebního procesu a ve výjimečných případech bylo použito jako způsob technické likvidace celého hlubinného dolu.

Příkladem výjimečné likvidace hlubinného uhelného dolu byla likvidace Dolu Jan Šverma v Žacléři ve východních Čechách. Likvidace proběhla založením hlavních důlních děl i všech podzemních prostor základkovou směsí vyrobenou z průmyslových odpadů. Hydraulické základkové směsi používané v hlubinných uhelných dolech již v minulosti byly založeny na využití flotačních hlušin z úpravy uhlí a popílku a strusky z elektráren a tepláren. Výzkumné práce a praktické zkušenosti rozšířily vstupní komponenty těchto základkových směsí na celou řadu odpadů z hutnictví železa, odpady z uhelného hornictví a odpady z energetiky vznikající spalováním uhlí. Dále zde byly použity odpady z cementářského průmyslu, odpady vznikající při zpracování kamene a některé další průmyslové odpady.

Výjimečnost likvidace Dolu Jan Šverma v Žacléři spočívala v krytí převážné části nákladů této činnosti poplatky původců průmyslových odpadů za jejich předání zpracovateli těchto odpadů.

Z této skutečnosti vychází možnost řešení ekonomických problémů spojených se zakládáním podzemních prostor, především při likvidaci dolu.

Z ekonomického hlediska je technická likvidace dolu ztrátová činnost. Po ukončení těžby lze počítat pouze s omezenými zdroji výnosů z likvidace – např. prodej strojů, materiálu z likvidovaného dolu. Za základní faktory ovlivňující ekonomiku zakládání považovat (i) cenu za odběr průmyslových odpadů ke zpracování (ii) množství zpracovaných průmyslových odpadů (iii) variabilní náklady spojené se zpracováním odpadů a ukládáním základkových směsí (iv) trvalé náklady likvidovaného dolu.

Důležité je zjištění, že poplatky za odběr průmyslových odpadů mohou pokrýt většinu nákladů spojených s likvidací dolu zakládáním. Praktická likvidace Dolu Jan Šverma ukázala, že zaplnění všech podzemních prostor eliminuje bezpečnostní a environmentální problémy spojené s uzavřenými doly. Navíc se definitivně vyřešil problém více než 640 000 tun průmyslových odpadů, které by v původní formě byly ukládány na povrchové skládky. Tyto skládky z dlouhodobého hlediska představují riziko pro životní prostředí.

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