

Ecological aspects of filling of worked-out area during underground coal mining

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Abstract. The ecological consequences of underground coal mining and the mechanisms of transformation of the rock mass and the earth's surface are determined. To increase the efficiency of environmental activities of coal mining enterprises, the expediency of introducing the technology of stowing of the worked-out areas with grouting solutions using rock from dumps, ash, waste from coal processing plants is substantiated. The implementation of the proposed technological solutions will ensure the protection of land, buildings and structures from under-mining, as well as improve the environmental situation in coal mining regions.

1 Introduction

The coal industry is the basis for the sustainable functioning of the national economy and its energy security [1 – 5]. Underground coal mining is accompanied by a complex negative impact on all components of the environment [6 – 9]. In most cases, the development of coal deposits in Ukraine is carried out by obsolete and worn-out mine fund in difficult mining and geological conditions [7 – 12]. Chronic underfunding of coal mine greening programs leads to significant changes in the ecological status of their areas [13 – 18]. In terms of environmental impact, the coal industry predominates among other industries, having a detrimental effect on surface and groundwater, soil, subsoil and landscape [17 – 21].

Coal mining in the country lasts more than 200 years, so in the coal-mining regions there is deformation of the earth's surface, flooding and salinization of land, pollution of groundwater and surface water, exacerbating socio-economic problems and forming depressed areas [17, 19, 22 – 24].

Subsidence of the earth's surface is another problem that is not taken into account when operating and closing mines. In mining regions, a large area of land to some extent affected by the negative effects of subsidence and local relief changes: the formation of man-made lakes, physical destruction of buildings and structures, damage to infrastructure, waterlogging of agricultural lands, flooding of settlements, etc. [24 – 28].

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Prospects for the development of coal mining in different countries are ambiguous and depend on many factors: geological reserves, mining and geological conditions, the level of profitability of coal mining, the place and role of coal in the fuel and energy balance, environmental constraints, the degree of economy integration in regional and global structures. Coal mining has become profitable only in those enterprises where there were favourable mining and geological conditions or mining technologies were used with minimal impact on the environment, including the use of coal gasification methods [29 – 35].

The coal industry is the key to the successful establishment of Ukraine's energy independence, but at the same time it provokes a number of problems that inevitably accompany the extraction of minerals. At the same time, there are almost no long-term programs and projects aimed at the inevitable future liquidation of enterprises that would guarantee environmentally friendly decommissioning of mines. Thus, for increase of ecological safety of functioning of the coal mining enterprises it is recommended to introduce technological schemes of working off of coal seams with a stowing of the worked-out area.

2 The research problem setting

Long-term coal mining has led to significant changes in the stability of rocks and the earth's surface in the coal-mining regions of Ukraine. The main reasons for such changes are [36 – 43]:

- increase cracking and decrease the strength of rocks;
- stratification and hanging of rocks in the marginal parts of workings;
- the presence of voids in the stope workings;
- changes in hydro- and gas conductivity, hydrodynamic structure of groundwater, formation of local and general depression funnels;
- large-scale subsidence of the earth's surface;
- the presence of a significant number of vertical and inclined workings with access to the earth's surface, which are eliminated at different times and with different quality;
- under-mining of a significant number of buildings, structures and infrastructure.

The most complex transformations occur during mining operations in conditions of geological disturbances (folded rocks bedding and the presence of fractured tectonic displacements in the under-mined mass), as well as during the development of steep seams. Under such circumstances, there is an abnormal development of displacement processes, which causes significant changes in the state of the environment, waterlogging of lands and degradation of agricultural lands [44 – 47].

The issue of development of shifts at different stages of the life cycle of a coal mine is important for [48 – 50]:

- establishing the moment of cessation of the impact of coal mining technologies on the stability of the rock mass;
- identification of the beginning of the processes of rock mass activation caused by the subsequent liquidation of the coal mining enterprise.

The development of the process of deformation and subsidence of the earth's surface begins immediately after the lowering of the roof over the worked-out areas. The subsidence rate of the earth's surface depends on the thickness of the seam, the method of roof control, the speed of advance of the face, as well as the position of a particular point in the shift trough [36 – 43].

At present, a significant number of cases of surface failures under buildings and industrial facilities in areas previously mined-out by workings have been recorded in most coal mining areas [44 – 50].

The presence of a significant number of storage ponds of mine water, tailings and sludge storages and other infiltration feeding facilities in coal-mining regions leads to a steady rise in groundwater levels and the development of the process of flooding. This is due to increased filtration of man-made pollution from surface accumulators of solid and liquid waste, as well as the interaction of zones of geochemical soil contamination.

The main factors that necessitate the use of stowing of the worked-out area in coal mines are:

- protection of land, buildings and structures from under-mining;
- increasing the stability of the side rocks in the working space of the face;
- increasing the stability of development workings in order to reuse them;
- utilization of rock from carrying out development mine workings.

The need to use the technology of extraction works with the stowing can be caused by one or more of these factors.

3 Assessment of the environmental consequences of the operation of coal mines

Coal mining by mines (and later in the development of reserves and their elimination) increases the impact of mining on the environment due to factors such as: flooding and waterlogging of areas because of rising groundwater levels, as well as salinization of soils; change of river runoff modules; emergence of new and restoration of old extinct springs with water of increased mineralization; man-made impact on the state of the earth's surface, natural and other objects; change of engineering and geological conditions (occurrence of landslides, development of ravines, etc.); change of seismic resistance of the rock mass; pollution of atmospheric air, water bodies and soils, etc.

To date, a significant amount of research has been conducted to identify environmental impacts on environmental components arising from the operation of certain technologies and processes [51 – 56]. At the same time, there is a need for comprehensive identification of environmental and man-made consequences of subsidence of the earth's surface, flooding and waterlogging of agricultural lands, release of mine gases on the earth's surface, catastrophic environmental changes, etc. that occur during coal mining [57 – 59]. For effective management of environmental safety in coal-mining regions, there is a need to develop criteria that will most adequately characterize the levels and consequences of environmental damage in the territories of coal-mining regions.

To identify the types and sources of environmental hazards that occur at different stages of field development, the intensity and frequency of occurrence and consequences of the impact of technological processes of coal mines on the state of the environment are analysed in points: 0 – no impact; 1 – minimal or indirect impact; 2 – periodic direct or indirect impact; 3 – continuous direct impact. The results of expert environmental assessment of the consequences of the operation of coal enterprises are given in Table 1.

As a result of the analysis of table 1 it's obvious, that the activity of the coal mine has a negative impact on almost all components of the environment. Atmospheric air has the least negative impact, the source of pollution of which is mainly waste heaps.

In this case, during coal mining there are: violation of the dynamic and chemical regimes of the hydrosphere; flooding of the earth's surface in conditions of watering rock mass; activation of rock thickness shift processes disturbed by repeated under-mining during water saturation; change of physical and mechanical properties of bases of buildings and constructions at soaking of soils; intensification of gas evolution, etc. Given the significant negative impact of coal mining processes on the stability of the mountain massif, there is a need to justify ways to minimize these effects.

Table 1. Expert assessment of environmental and man-made consequences of the operation of coal mines.

Types of influence	Objects of influence				
	Atmosphere	Hydrosphere	Lithosphere	Soils	Biota
Decreased stability and hardness of rocks	0	2	3	2	1
Deformation of the rock mass	0	3	3	3	3
Subsidence of the earth's surface	0	3	3	3	3
Water-saturation of the rock mass	0	3	3	2	2
Violation of the hydrological regime	0	3	3	3	2
Depletion of aquifers	0	3	2	3	2
Pollution of surface water bodies	0	3	2	1	2
Migration of pollutants	2	2	2	2	2
Mixing of mine waters with drinking waters of underground horizons	0	3	1	2	2
Flooding and waterlogging of lands	0	3	3	3	3
Allocation of land for waste heaps	1	1	3	3	2
Deformation and destruction of buildings and infrastructure	1	2	3	3	2
Formation of explosive methane-air mixtures	3	1	1	2	3
Emission of mine gases to the earth's surface	3	1	2	2	2

4 Requirements to technological schemes of working off of seams with a stowing

To increase the efficiency of environmental activities of coal mining enterprises, it is recommended to introduce the technology of stowing of the worked-out area. As materials for preparation of grouting solutions it is supposed to use rock from dumps, ashes, wastes of concentrators, etc.

When stowing of the worked-out area in order to prevent dangerous subsidence of the earth's surface, the main purpose is to ensure the maximum density of the filling mass. This requirement is especially important for the conditions of the mines of the Western Donbas, where subsidence of the earth's surface reaches significant values. Increasing the density of the filling mass can be achieved through the use of stowing materials with high compression properties by adding, for example, to the mine rock 25 – 30% sand; the use of the embedded pipeline with the end release of the rock or the side outlet with a slight deviation of the trajectory of the stowing material from the axis of the pipeline; the correct choice of the distance between the releases of the rocks, the optimal irrigation parameters. The filling mass should not have voids and if possible, should occupy all the worked-out area between the roof and the sole.

An important requirement to ensure minimal subsidence of the earth's surface is also to reduce the convergence of lateral rocks in the working space of the long face. The magnitude of the convergence of the side rocks, proportional to the width of the working space, so it is necessary to bring as close as possible to the face of the formation of the filling mass and ensure the timeliness of its construction.

Studies have shown that when the roof is fully filled, the stability of the side rocks in the working space of the long face increases, in many cases the load on the mechanized support is reduced. Therefore, a full stowing in the mines of the Western Donbas is technically feasible to use, primarily in the development of formations in difficult mining and geological conditions.

The projects of the mines of the Western Donbas did not envisage the construction of stowing complexes, so it is quite difficult to lower and transport the filling materials from the surface to the breakade face without reconstruction of the mines. In addition, the "tails" of the enrichment are significantly waterlogged and cannot be used as filling material without prior drying.

Taking into account the experience of domestic coal mining enterprises, it will be expedient to equip underground precinct crushing and embedding stations, using rock as a filling material from development workings and rock cuts in long faces.

Development workings in the considered area are carried out on coal with a notch of lateral rocks. Therefore, in order to use rocks as filling material, it is necessary to separate coal from them. This requirement can be achieved by separate transportation of coal to the surface, and overburden – to the crushing-embedded complex, as well as the use of continuous and combined development systems in the conduct of development workings after the long face.

When filling cut rocks in the worked-out space from the separate excavation of coal and rock, the main requirements for the technological scheme are ensuring a clear interaction between the processes of excavation and stowing; minimum coal content in filling materials. To do this, the performance of filling equipment must correspond to the performance of the excavation complex, and the downtime of each of the links must have minimal impact on the performance of the other link.

When choosing technological schemes, it is also necessary to strive to create a unified technology that will develop seams without dangerous subsidence of the earth's surface, reuse development workings and provide small production wastes.

5 Assessment of environmental efficiency of working coal seams with a stowing of the worked-out area

To increase the environmental efficiency of the coal mining enterprise, it is recommended to introduce technological schemes of coal seams development with a stowing of the worked-out area. The results of expert assessment of environmental efficiency of the proposed technological solutions are given in Table 2.

Analysis of the data in Table 2 revealed that the application of the technology of stowing of the worked-out area will minimize the negative consequences of the operation of coal mining enterprises. At the same time, there will be a gradual reduction of the negative impacts of the company on almost all components of the environment. Early introduction of environmental technologies will reduce the negative consequences of the operation of the mining enterprise, and especially in the post-liquidation period.

Table 2. Expert assessment of ecological efficiency of technologies application for a stowing of the worked-out area at the coal mining enterprises.

Types of influence	Objects of influence				
	Atmosphere	Hydrosphere	Lithosphere	Soils	Biota
Decreased stability and hardness of rocks	0	1	1	1	1
Deformation of the rock mass	0	1	1	1	2
Subsidence of the earth's surface	0	1	1	1	2
Water-saturation of the rock mas	0	2	1	1	1
Violation of the hydrological regime	0	2	1	1	2
Depletion of aquifers	0	2	1	1	1
Pollution of surface water bodies	0	2	1	1	2
Migration of pollutants	1	1	1	1	1
Mixing of mine waters with drinking waters of underground horizons	0	2	1	1	2
Flooding and waterlogging of lands	0	1	1	1	2
Allocation of land for waste heaps	1	1	2	2	2
Deformation and destruction of buildings and infrastructure	1	1	2	2	2
Formation of explosive methane-air mixtures	2	1	0	1	2
Emission of mine gases to the earth's surface	2	1	1	1	1

6 Conclusions

As a result of the research, the following conclusions can be drawn:

1. The identification of environmental and man-made risks that occur at different stages of coal development, found that the highest levels of environmental risks occur during the deformation and subsidence of the under-mined rock mass and the earth's surface.

2. To prevent deformation of the earth's surface and damage to infrastructure, the possibility of using the technology of integrated stowing of the worked-out areas of mines is substantiated.

3. The use of stowing of the worked-out areas in coal mines will protect land, buildings and structures from under-mining; increasing the stability of the side rocks in the working space of the breakade faces; increasing the stability of development workings in order to reuse them; utilization of rock from carrying out development mine workings.

4. Timely implementation of environmental measures at coal mining enterprises will reduce the level of environmental hazards of coal mining processes. It should be noted that the implementation of the proposed measures will be effective only if they are implemented at the existing coal mining enterprise, and this will reduce the levels of environmental danger in the further elimination of unprofitable coal mines.

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