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Quality estimation of influence of energy resources extraction on environment in Ukraine

The article features the impact of technological extraction processes of basic Ukrainian energy resources on the environment – i.e. coal and gas extracted by means of open mining, underground mining and bore mining. The authors discuss qualitative indicators of the negative impact of preparation and mineral extraction processes on different biosphere components. The article presents a comparative table of the impact indicators, like the nature, size and duration for different extraction methods. Finally, prospective ways were shown how to develop the energy resources base in Ukraine.

Keywords: *energy resources, environmental impact, extraction method, biosphere components*

1. INTRODUCTION

It is hardly possible to imagine a modern country without energy resources, i.e. the resources of electrical, mechanical, chemical, or nuclear energy. However, the distribution of energy resources in the world is irregular, some countries have abundant resources, the others – limited ones. Due to this fact the majority of countries depend on other countries in this respect. It would seem that in the civilized world there should be mutual responsibility in this domain, manifested by the exchange of resources and products. Such a situation would foster the overall development of humanity. This is not the case, though. International relations are described by instability which leads to crises and conflicts, both local and global. This is characteristic not only of modern Ukraine but also other European countries with similar problems, and breaches normal functioning of these countries. In order to mitigate possible inconvenience in international commercial relations, a country and its industry should create their own reserves for short-term disturbances in resources delivery or develop their own resource bases in case of long-term problems. The most reliable way to do it is to apply a "mixed" method combining the two above options.

Nowadays the extraction of gas, oil and coal does not provide full energetic safety of our civilization. This is particularly important for Ukraine which has very limited amount of energy resources indispensable for the country to function.

Therefore geological survey and extraction of coal, gas-coal and gas-oil deposits in sedimentary rock becomes an issue of national safety. An important related issue is the necessity to assess possible negative impact of energy resources extraction and to minimize possible hazards. Ukraine's energetic potential consists of coal deposits, which are expected to last for about 300 years, quite limited deposits of oil and deposits of natural gas and shale gas, preliminarily estimated as several quintillion cubic meters.

Ukraine has significantly large deposits of radioactive ores, still, the country lacks technological infrastructure to prepare fuels from these resources. There are also rich resources of peat. Each year the country accumulates the reserves of vegetal (renewable) biomass energy resources in the form of wood, bushes and straw. There is a large potential in the so called unconventional energy sources (wind, geothermal heat, solar energy and others), however their exploitation requires significant capital expenditures and time – and there is a lack of both.

While preparing one's own energy resources base it is necessary to consider the impact which results from human activities. First of all, this refers to ecological issues. With low production culture, practically any technology of mineral resources extraction may cause significant damages to the natural environment – impossible to remove for decades. Such a threat evokes certain feelings in the society, opinions and confrontational behaviour which are often emotional and lack objective justification. Therefore, while assessing the impact of mines on the natural environment one has to apply a scientific approach and reliable information. This should be the basis to predict an organization's operations already in the design phase and should constitute certain recommendations for state- and community-level monitoring of these operations.

The objective of this article is to determine quality aspects of processes which take place in the natural environment while extracting coal by means of open mining and underground mining and while extracting oil by bore mining. To better fulfil the objective, it is worth presenting some general information about the biosphere – an environment which is a zone of life and energy resources. The biosphere is the ambiance of the Earth, a space where all living organisms function. In other words, the biosphere is the zone of Earth in which life is possible.

Several components of the biosphere are distinguished. They differ from one another in terms of quality. The first one is the lithosphere – a rigid outermost shell of the Earth. Here the basic flammable energy resources are deposited, such as biomass, peat, coal, gas, and oil. The hydrosphere is the mass of water on, under and above the Earth. The atmosphere is the layer of gases surrounding the planet. An integral part of the biosphere are different physical fields which lack rest mass but affect material objects: gravitation, temperature, different-range electromagnetic radiation, elementary particles flows, pressure, and others. Many of these fields occur not only in the terrestrial space but also in our solar system and the whole universe. The connection of these fields parameters allows the basic mass of water to be in a liquid state, which is a universal dissolvent and environment for chemical and physical reactions of substances. In the process of evolution a specific form of matter developed in the Earth. The matter consists of organic cells or biota, represented by bacteria, fungi, flora and fauna.

Powerful biochemical processes that were taking place in the Earth during the period of 5-6 billion years resulted in the current geological and climatic state of the planet. Another evolution stage was the appearance of humans. The formation of peoples and nations led to the establishment of countries, religious-, cultural-, scientific-, and educational institutions, offices, organizations, etc. This stage of the biosphere development is called noosphere, a term introduced by a Ukrainian scientist Vladimir Vernadsky.

The noosphere consists of the anthroposphere (community of people as organisms), the technosphere (artificial objects made by people and natural objects modified as a result of human activity) and the sociosphere (social factors characteristic of the given stage of people's development and their mutual relations with nature). The active function of the noosphere lies in securing the growing needs of humans, resulting from the rapid development of the Earth's population and increasing needs of this population. These objectives can be fulfilled by instruments, machines, trade, industry, and agriculture developed and undertaken by people. All these aspects relate to the technosphere which was developing intensively in the period of 2-3 centuries after the industrial revolution. The technosphere depends on the noosphere and cannot function separately.

When assessing the impact of minerals extraction processes on the natural environment, first it is necessary to determine the components (character), scale (volume, surface and others) and duration of the impact of particular technological operations, or their types, on the biosphere elements.

2. TECHNOLOGICAL PROCESSES OF COAL EXTRACTION BY OPEN MINING

After the geological survey and design works a deposit is prepared for exploitation. The ecosystem of an opencast mine and its natural surroundings contains not only the mining excavation as such but also certain facilities on the surface which are indispensable for the mine to function. This infrastructure includes roads, railways, power lines, pipelines, and canals responsible for the drainage of mine and surface water. The ecosystem also covers sanitary and protection zones around stationary emission sources, rock dumps, water tanks, sedimentation basins, and other objects.

The impact of opencast mines on the landscape is manifested by modifications in the lay of the land and appearance of technogenic forms – negative (denudation) and positive (accumulative) ones. According to today's requirements, the surfaces used for buildings and other facilities of an opencast mine (openings, workshops, storage buildings, outside dumps, tanks and basins, accommodation units, pipelines, railways and roads, power lines, power substations, etc.) should be located, if possible, in the areas with no agricultural and forest importance. However, mining facilities often occupy surfaces of several dozen hectares, so it is difficult to fully comply with these requirements. In each case the preparation of the site starts with the removal of the fertile soil layer and its deposition on unoccupied spaces with the purpose of later reclamation. While the deposit is extracted, the working space of the opencast mine is also prepared for spoil removal but first the soil layer is removed. Unfortunately, modern methods of dump-based storage of soil do not ensure that the soil remains fertile. What is more, after several or several dozen years of storage the soil properties undergo degradation.

The construction of an opencast mine causes significant changes in the landscape and, from the point of view of ecology, it breaches the balance of the natural environment. The key objects of the mine are: mining excavation and outside dumps (Fig. 1).

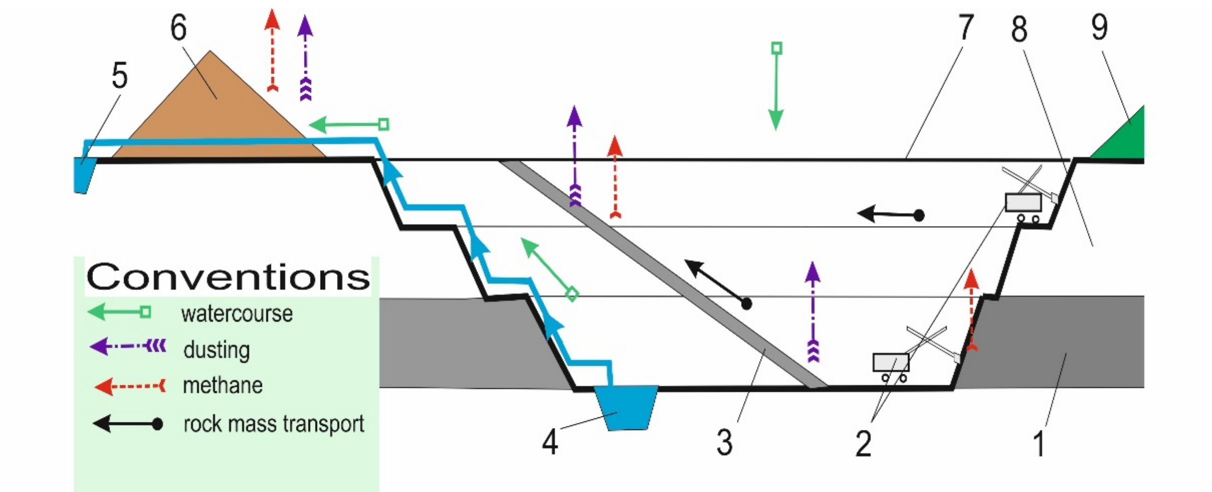

Fig. 1. Scheme of technological process of coal extraction by open mining:
1 – coal seam; 2 – winning machine; 3 – transport drift; 4 – sump; 5 – water draining device; 6 – outside dump; 7 – surface; 8 – spoil; 9 – fertile soil layer

Exploitation works include the following basic production processes: winning, loading, transport and shipment of mineral resources. In open mining the winning process is based on separating mineral resources from the rock mass with simultaneous loosening of the rock. The latter is performed by means of blasting or with the use of different mechanisms and machines. When the coal seam is developed and extracted, and the spoil and coal are transported, loaded and unloaded, there are significant volumes of rock dust and coal dust emitted, whose overall weight is estimated at 1-2% of the developing and exploiting mined rock flows.

If the roof of the seam is made of consolidated rock, its crushing is performed by blasting. Usually, several dozen holes filled with tonnes of explosives are fired. This results in significant distortions of the rock mass on a large area. Besides, the explosions are accompanied by strong acoustic waves which disturb the balance of the ecosystem.

With the proceeding coal extraction methane and other polluting gases are emitted from the seam. Their volume is estimated on the basis of the seams gas content and the layers of barren rock.

During the exploitation of brown coal seams by means of open mining there are cases of self-ignition. As a result of that, a significant amount of toxic and greenhouse gases is emitted. The volume of the emission generated during a fire can be assessed based on the volume of burnt coal. Self-heating and self-ignition occur too when brown coal is stored on dumps or in silos, particularly after rain and due to wind.

In opencast mines there are also open fires which originate when the mine facilities or electrical devices start to burn due to external energy. In this case the volume of the emission should be assessed based on the type and amount of burnt substances.

During the construction of an opencast mine and during its preliminary operations the spoil rocks are located on the surface in the form of cone-shaped dumps, crests, flat-top elevations, and others. The mass of rocks accumulated on the dumps amounts to several dozen million tonnes. The weight of this material causes lowering of the surface on which the material is stored and rising of the floor beyond the limits of the dump. As a result of that, waterlogged land originates around the dumps. What is more, the infrastructure elements located in the dumps vicinity get deformed (buildings, roads, pipelines, power lines, etc.). The observations undertaken so far have proven that negative phenomena of floor deformation were registered at a distance of 100 m from the dumps (Fig. 2).

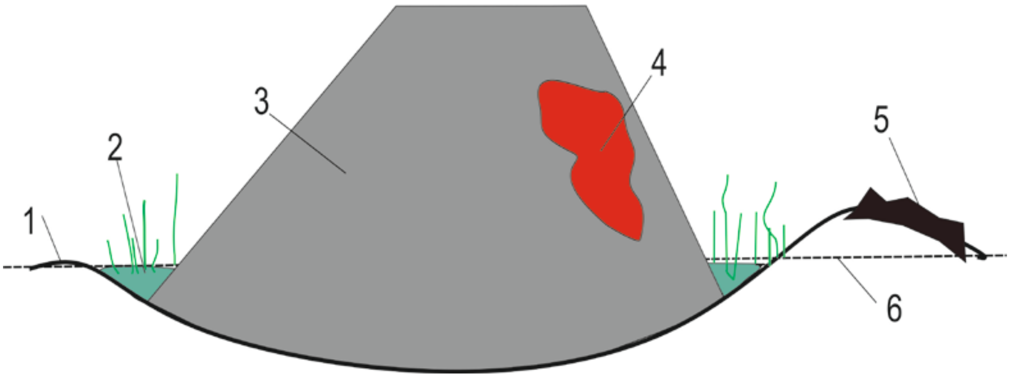

Fig. 2. Scheme of negative impact of rock dump: 1 –profile of deformed surface; 2 – waterlogged part of the surface; 3 – rock dump; 4 – source of self-heating or burning; 5 – deformed road; 6 – original surface level

The mass of dumped rocks consists of minerals containing significant amounts of coal, sulphur, phosphorus, iron, and other elements which, in the presence of water, react with oxygen in the atmosphere. These are exothermic reactions related to heat emission. This process also employs bacteria which, feeding on pirytes, produce elemental sulphur. This kind of sulphur burns very violently and, reacting with moisture, creates concentrated sulphuric acid vapours. These factors lead to the generation of self-heat and self-ignition sources whose presence causes disturbances in the gas and heat balance of the opencast mine ecosystem.

The temperature of rock mass at the depth where exploitation works are conducted is several degrees higher than the average annual temperature on the surface. Such temperature differences determine the changes in heat balance and evoke climatic disturbances of the ecosystem.

The development of excavations (half-pits, levels, holes, etc.) disturbs the system of surface and underground water streams forcing them to flow towards the opencast mine excavation. In order to change the flow direction to the opposite one, special canals and ditches are constructed. This, of course, causes significant changes in the ecosystem.

3. TECHNOLOGICAL PROCESSES OF COAL EXTRACTION BY UNDERGROUND MINING

In the case of underground mining, the boundaries of the underground mining area and those of the surface mining facilities do not coincide. The area of the mine covers the surface of shafts, test pits, industrial areas, dumps, as well as such facilities as road and railways working for the mine.

In this area and in its vicinity the basis (background) of the biota is subject to degradation or total destruction. The technosphere objects affected by mining exploitation require renovation or transfer to a different place. Here it is important to note the negative impact of underworking of surface buildings and objects located beyond the boundaries of the mine but still on the mining area [5].

The impact of underground excavations on the landscape results in the following elements occurring on the surface:

- rock dumps from open deposits and waste rock;
- tanks for flotation tailings and slurry where waste rock, remaining after ore enrichment, is deposited;
- caves and cavities of different shapes and depths.

Caves and cavities on the surface result from roof falls. They differ in terms of shapes and sizes, thus it is possible to distinguish the following:

- subsidence troughs occurring after the exploitation of deposits of middle (1.5-3 m) and high thickness with horizontal, saddle or flat beddings. The troughs of the rock mass are located in the retarded caving zone. When the seam is very thick and steep, it is possible to have trough-like terraced caves – subsidence troughs in this case will be directed towards the caving (Fig. 3);
- chimney (canyon) caving occurs above the goafs of thick, flat or steep deposits. In these conditions subsidence troughs are often located in the caving zone;
- circle-shaped caving can occur in places where steep deposits are exploited.

Bare rocks within the retarded caving zone, waste dumps surfaces, tanks and slurry basins are often sources of dust. Moreover, during the exploitation of energy resources, phytotoxic elements carried by dust and smoke may penetrate to the air. They may occur in groundwater which forms its chemical composition in subsidence troughs and dumped rocks. This way, apart from their impact on the lay of the land, underground excavations may also cause pollution of fertile soil, plants and underground water.

The sizes and shapes of dumps depend on a few factors, particularly on the technologies of deposits extraction and dumps formation. To put it simply, cone-shape dumps are formed with the use of wagons and skips, flat-top elevations and crests – with car and rail transport, while multi-layer dumps shaped as terraced platforms are formed when the amount of the dumped rock is big. Flotation tailings and slurry tanks in processing plants and power engineering plants (electrical power plants, heat generation plants) are usually located next to ground depressions. These depressions are gradually filled up creating flat or flat surfaces. The flotation tailings and slurry tanks can be elevated above the ground level with the use of ramparts. Then they have a form of flat elevations surrounded by slopes whose curves are determined by natural descent of the rocks the rampart is made of.

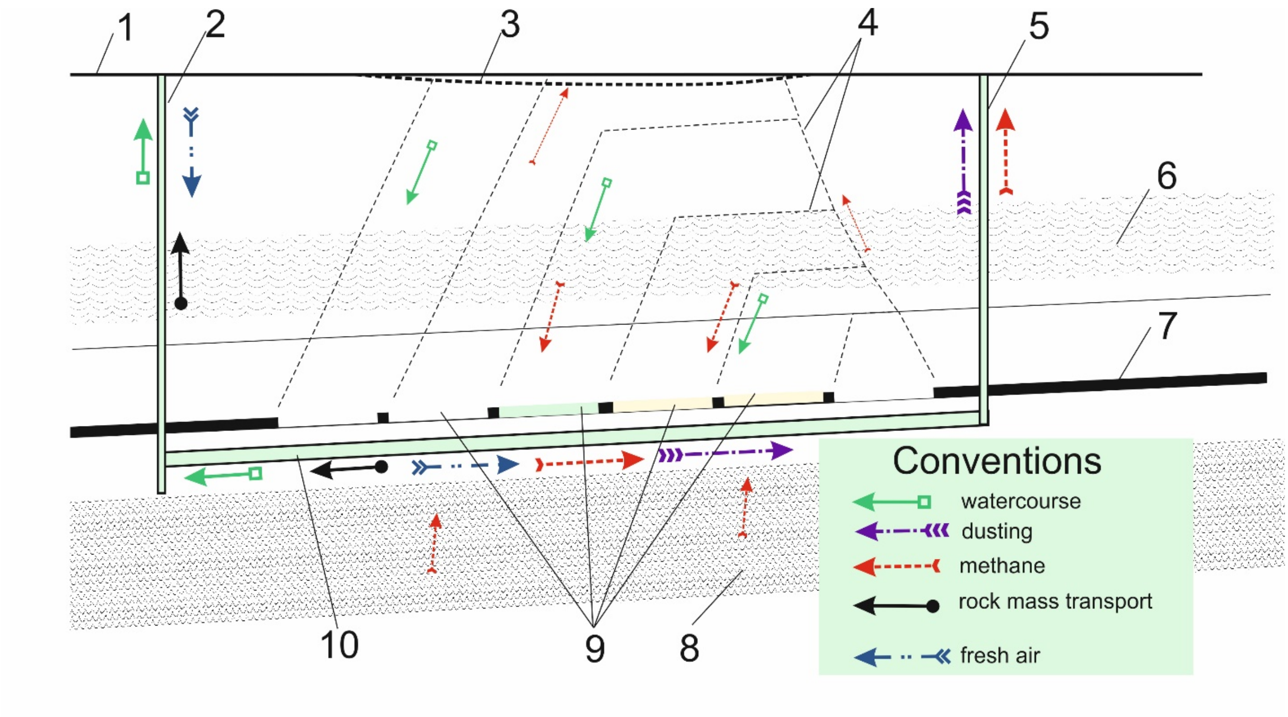

Fig. 3. Scheme of technological process of coal extraction by underground mining: 1 – ground surface; 2 –ventilating shaft; 3 – trough; 4 – cross sections of virgin rock; 5 – ventilating shaft; 6 – methane sandstones of seam roof; 7 – coal seam; 8 – methane sandstones of seam roof; 9 – goafs; 10 – main excavation

The negative impact of rock dumps on the natural environment is, basically, similar to that observed in open mining. Thus the following phenomena occur:

- rocks burn and significant amounts of toxic and greenhouse gases are emitted;
- liquid substances containing coal are washed off dumps, while surface and ground water is polluted with phenols as a result of precipitation;
- wind erosion causes that significant amounts of low-radioactive dust coming from burning rock dumps rise into the air;
- clouds of hot dust are dispersed in long distances causing tree leaves within the radius of 400 m to char;
- the ground is loaded with amassed rock dumps and forced out; as a result of that ramparts are formed which damage the neighbouring railways, roads, pipelines, power lines, buildings, and other facilities (the impact of the ground movement was registered as far as over 100 m from the dumps);
- increased humidity of waste dumps results in landslides and mud flows;
- when the weather is dry and sunny there are frequent landslides of rocks on the dump slopes; this is related to changes in physical and mechanical properties of the drying material;

- deposits are contaminated with waste products – as a result of mining there are significant amounts of metal, oil products, explosive products, wood and other materials left under the ground;
- excavation driving processes result in breaching the continuity of the rock mass; hydrological and geological character of surface and underground water is changed – the water flows towards the excavations which increases the risk of flooding;
- technological operations related to mining, loading, transport, and dumping generate dust which significantly worsens the atmosphere of the ecosystem;
- during exploitation works carboniferous rocks emit a large amount of greenhouse gases consisting basically of methane and carbon dioxide;
- boiler plants, coherent plants, vacuum pumps and other stationary devices emit greenhouse and toxic gases to the atmosphere;
- fans generate noises which exceed admissible limits;
- the surface of the dump is a source of increased radiative background.

The above list shows that the scale of contamination due to underground mining is similar to that of open mining while the negative impact is even greater in some cases.

4. TECHNOLOGICAL PROCESSES OF ENERGY RESOURCES EXTRACTION BY BORE MINING

The technology of bore mining requires that drilling fields should be prepared, i.e. platforms, roads, liquids and slurry tanks, and other types of facilities should be constructed. For the purposes of the deposit exploitation it is necessary to construct pipelines. All these undertakings result in significantly large areas of land being covered by industrial facilities and slurry storage facilities (Fig. 4).

Bore mining of gases and other minerals is accompanied by a number of negative phenomena, such as: waste gases generated by internal combustion engines, emergency gas emission occurring during the seams opening or during fires, degradation of the basic biota, disturbances of the technosphere background, heat emission, noise pollution, or exceeded radiation background. Currently, a good solution that neutralizes the impact of these factors is the use of directional drilling which allows to reduce the number of vertical drills and diminish this type of negative impact.

Fig. 4. Typical view of an area where gas deposits are exploited

Currently, vertical degasification holes are drilled in carboniferous rock mass according to both traditional and directional methods. A directional hole in the San Juan basin (Colorado, USA) drains almost seven times more methane from virgin seams than from an average vertical hole. It is estimated that in this basin it is possible to obtain 50-75% of the total deposits of methane with the use of directional drilling. Such efficiency is much better than with the use of standard degasification methods. Besides, directional drilling allows to reduce significantly the number of drilling sites and the indispensable infrastructure accordingly.

The network of horizontal directional holes, where cracking is performed, evokes stress changes and deformations of a significant part of the rock mass. As a result of that a large volume of methane will pass into a free state. The diffusion time of the total volume of gas from the rock mass can be from several minutes to several dozen years. The latter period is much longer than the operating time of drilled holes. Residual free methane gradually rises to the surface, finding fissures and cavities, including geological disturbances of the rock mass. This methane will appear on the surface in several or several dozen years. In analogical conditions in hard coal mines the methane occurs in explosive concentrations and destroys the biota on the surface.

Table 1.

Qualitative assessment of the impact of different types of energy resources production on the biosphere components

Biosphere element	**Impact indicator**			**Energy resource extraction method**		
	Nature	**Size**	**Time**	**Open mining**	**Under-ground mining**	**Bore mining**
Lithosphere	Large area of land occupied by mining facilities	Area of mining facilities	Period of the mine operation	+	+	+
	Breaches of landscape			+	+	+
	Mudded surface near external dumps	Area of mechanical protection zone	Until the dump is reclaimed	+	+	–
	Deposit goafs contaminated with industrial waste	Area of goafs	For good	-	+	+
Hydrosphere	Changes in hydrological system	Mining area	Period of the mine operation	+	+	+
	Worse quality of running water due to dumps	Volume of dumps		+	+	+
	Surface water contaminated with solutions after cracking	Volume of solutions drained after cracking	Until the solutions are processed	–	–	+
	Deposits contaminated with residual solutions after cracking	Volume of solutions left after cracking	For good	–	–	+
Atmosphere	Dust generated due to mining, transport, processing and storage	1-2% of the extraction output	Period of the mine operation	+	+	+
	Emergency emission of gases during fires	Proportionally to the burned volume	Until the fire is extinguished	+	+	+
	Emission of mobile sources	Fuel consumption	Period of the mine operation	+	+	–
	Emission of stationary sources	From the emission sources to the limits of sanitary and protection zones		+	+	–
	Emission of greenhouse gases from the seam	Proportionally to the output of extracted coal	Period of the mine operation	+	+	–
	Emergency emissions from rock dumps	Proportionally to the area of burning	Until the fire on the dumps is extinguished	+	+	–
Biota	Degradation of the original biota	Area of (sanitary) protection zones	Period of the mine operation	+	+	+
Noosphere	Disturbances of technosphere background	Area of the industrial facility		+	+	+
	Seismic damages of technosphere objects	In the propagation zone of explosion-generated vibrations		+	+	+
Physical fields	Increased radiative background	Area of the dump and level of radiation		+	+	+
	Noise pollution	Level of noise		+	+	+
	Heat emission	Temperature of gases and volume of extraction output		+	+	+

A decisive factor in methane extraction from coal seams is the permeability of the rock mass understood as the combination of its natural porosity and microporosity caused by cleavage (natural separation of coal). The use of modern technologies of gas extraction from sedimentary rocks allows to reduce the sizes of slurry tanks and drilling fluid tanks and to achieve compact sites for drilling rigs.

In order to create or enlarge fissures, a fluid with a filling material is forced into the seam while its speed and pressure are gradually increased. Eventually, the seam is not able to absorb the fluid as quickly as it is forced into the fissures. At that moment the pressure is high enough to separate the coal seam along the existing weak zones. Apart from the fluid, the fissures receive sand (or any other filler) thanks to which they remain open when the pressure decreases. This kind of holes stimulation by hydraulic fracturing increases methane drainage 5 to 20 times.

Underground water which is obtained from the holes is forced into isolated underground formations or used for irrigation. This water usually contains acidic sodium carbonate and chlorides. The deposit can also be contaminated with the fluids and solutions remaining after the cracking process. These solutions contain many organic and non-organic substances, however, the presence of benzole and phenol compounds, chlorides, oxygen, as well as high temperature and pressure, allow to put forward a hypothesis that dioxins will occur in the places of hydraulic fracturing of the rock mass.

The depth of gas seams is responsible not only for the quality and content of methane but also for the costs of its extraction. For example, in a shallow bedding (under 300 m), the process of forming a geological structure may cause the gas to leak out until the coal is covered by a sufficiently impermeable layer of rock. On the other hand, the depth of gas seams affects the cost of drilling methane-drainage holes from the surface.

The best illustrative method to estimate the level of negative impact of different resource production methods on the biosphere elements is to take into account their quality features and put them into a table [1-4]. In Table 1 each method of extraction is accompanied by the types of its negative impact on the biosphere (lithosphere, hydrosphere, etc.) elements. In addition, three basic parameters of this impact are presented: nature, size and time.

5. CONCLUSIONS

According to the data from the beginning of this century, the majority of coal mines in Ukraine are in poor financial condition. The costs of extracted coal, as well as the number of failures and accidents, are one of the highest in the world. The situation can be improved by complex exploitation of mining resources. This can be done by processing not only coal but also mined rock which contains barren rock, moisture and elements in the gaseous state.

The barren rock extracted in a mine constitutes up to one third of the transported mined rock. A sensible way to use it would be to leave it in the mine as a construction material or as an additive for building mixtures, e.g. for road construction. In the Donbas Coal Basin where the amount of water is, on average, five times smaller than in other regions of Ukraine, it is recommended to lead water waste to such a state that it could be used for technical and irrigation purposes. The statistics show that there are three cubic meters of mine water per one tonne of the extracted mineral.

A good solution for the future would be to utilize geothermal energy for the purposes of the mine and external users. An advantage of this energy resource is that it is not taxed and its deposits are practically inexhaustible – limited only by the duration of excavations through which the energy carrier passes.

The most advantageous solution is to take up the exploitation of carboniferous deposits as coal and gas deposits, i.e. simultaneous extraction of methane and coal. According to different assessments, the Donbas deposits have from 12 to 25 quintillion cubic meters of gas in the fixed state. Now, in the best of cases, we use only 20-25% of methane contained in the rock mass and passing into the fixed state in places where mining operations are carried on. A larger volume of utilized gas, processed into electrical energy and heat, will allow to lower the price of coal, increase the safety of underground operations and improve ecological conditions of sanitary and protection zones around mines.

Stable, safe and economically justified operations of coal mines can significantly improve Ukraine’s internal energy market. This, in turn, would increase the country’s independence of imported energy resources. In today’s conditions that would be difficult to achieve but the problem has to be solved in the future. Therefore now it is time to develop a strategy how to put these ideas into practice.

The issue of open mining of brown coal remains unsolved. The state-owned Aleksandriyaugol opencast mines do not work and a significant part of their unique, though obsolete, equipment was liquidated. The majority of opencast mines were converted into water tanks during the reclamation processes. What is more, the technologies of liquid fuels production that were used in Germany in 1940s or in the RSA for the last four decades have not found application in Ukraine so far. Quick revival will not be possible without significant investments in this domain.

The most reliable way for Ukraine to ensure energetic independence is to take up bore mining of oil and gas. This technology has the lowest and best manageable ecological risk. It is highly viable to increase the industrial deposits of gas when taking into account the gas accumulated in sandstone and shale. The most prospective direction to exploit Ukrainian deposits in an ecological way is to extract coal-bed methane simultaneously with coal. This was successfully employed by the A.F. Zasyadko mine. The implementation of state-of-the-art technological solutions, such as multi-thread "bunches" of directional holes, cracking and holes depression, results in several times bigger volumes of extracted coal at a sufficient safety level, including proper ecological safety level.

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