Hybrid opencast/underground process to mine Kuzbass coal deposits

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Abstract. Modular technological structures of mine sites adapted to hybrid coal mining technologies in Kuzbass, protected by the Russian Federation patents are proposed. These intangible assets are of particular value to business community focused on research and commercialization of the results of intellectual activity. Therefore, the intellectual property can be considered as a promising credit instrument in the scientific concept of “intellectual underground mine of coal opencast”. High efficiency of the hybrid method for development of coal seams exceeds the average profit in Kuzbass by 1.5 times. In the long term, the unmanned Highwall geotechnology is considered as an intermediate stage of the hybrid mining method, Highwall mining technology is a fully autonomous, mobile, high-performance and economic coal mining system that allows fully mechanized underground mining at an opencast.

1. Introduction
The long-term scientific-and-technological advance in the fuel and energy complex implies the high priority of coal mining technologies in terms of “intellectual opencast” and “intellectual mine“ concept permitting 15–20% reduction in coal production costs thanks to more efficient management of the intellectual property [1, 2]. So far, the present-day coal industry is distinguished for the poor scientific-and-technological potential and low innovation activities.

In Kuzbass the coal mining industry is based on new scientific approaches and innovative principles in construction of production facilities and structure-and-network theory to open gently sloping coal seam deposits. In 2017 38 fully mechanized mine workings actively operated with the coal production rate of approximately 80 Mt, viz., 2 Mt per a working in average. The modular geotechnological process for opening and preliminary development of coal seams was employed. Many-years experience serves the basis in development of technological solutions for autonomous modular mine sections at operating opencasts where the combined opencast-underground mining processes are used to extract flat-lying seams within the concept “intellectual mine at coal opencast”. The technological solution rests on the elaborate mining-technological procedure for opening and preliminary development of mine sections with adaptation to coal mining process at an opencast, including a high-performance stoping face with the use of the integrated unmanned deep seam mining (IDSM) process and a conventional complex geotechnology on extraction of coal seams of 3–5 and more meters in thickness.

At Institute of Coal, SB RAN, the modular mining-technological structures at mine sections adapted to hybrid coal mining technologies are developed and protected by Russian Federation patents.
These intangible assets are intellectual property of specific value for business activities, oriented to research and commercialization of intellectual products [6].

The research-technological grounds for the integrated development of coal deposits should be aimed at development and modernization of complex geotechnologies with respective intellectual property oriented to an innovation component of Patent portfolio, which cost can manifold exceed the cost of any other property owned by a coal mining company. In this connection the intellectual property can be considered as a perspective credit instrument in the integrated subsoil management [2].

2. Integrated deep seam mining

The authors’ research work is based on research and methodological findings of research scientists of IPKON RAS [7], IM SB RAS [8], and NTTs-NIIOGR on the integrated geotechnological development of coal deposits. The present research work resulted in a novel scientific concept on the complex process of integrated in-depth exploitation of coal deposits: one of three proposed applications is protected by Russian Federation Patent:

- the first one: open coal mining up to design depth according to the economic design criterion, the use of available underground transport infrastructure at the final operation stage;
- the second (open-underground bench): a single high bench known as Highwall without castigation of coal pit walls with unmanned component in integrated deep mining of coal seams and handling of broken coal through communication systems available at the opencast;
- the third: underground mining by modular geotechnological structure at mine sections with application available production infrastructure of a coal openpit.

In perspective long-term projects Highwall unmanned geotechnology, namely, an integrated deep seam mining (IDSM) can be considered as a component of hybrid openpit/underground mining process. IDSM is a completely autonomous, mobile, highly efficient and economic coal mining system allowing the complete mechanized underground seam mining at a coal opencast.

In the coal mining industry the complex geotechnologies comprise the information on integration of open and underground coal mining techniques in space and time, regularities in behavior of coal pit–underground mines system in a rock mass, as well as technical, economic, ecological and management interrelations.

The technological complex of the integrated coal mining process is considered as a combination of functionally interrelated facilities for open and underground mining operations to fulfill the design technological processes under restricted mining-geological conditions to realize the geotechnological potential.

Practical application of the integrated mining process in Kuzbass is dated back to 2000-s as a result of scientific-methodical substantiation of the complex physicotechnical geotechnology at Institute of Coal SB RAS and technico-economic justification of investment ventures at Sibirginsky coal open mine (Novosibirsk), Mokhovsky openpit (Baikaimsky Mine). In 2017 coal production by the integrated mining process reached 59424 thou t or 25 % of the total coal production at Kuzbass mines (Figure 1). 57 466 thou t fall on the underground mining and 124 560 thou t fall on open mining.

![Figure 1. Annual coal production by different mining processes.](image)
For the period from 2009 to 2017 coal production by the integrated mining process was increased more than twofold from 27 to 59 Mt/year in Kuzbass.

The coal production by the integrated mining process in Kuzbass was analyzed with singling out coal production by open and underground mining techniques separately, using the modular geotechnological structure at mine sections at coal opencasts with the use of available production infrastructure (Figure 2).

It is established that coal production at modular mine sections of coal open mines increased approximately 2.5 times for 8 years from 11.4 to 27.4 Mt. (The coal production share by open mining in the integrated mining process increased twofold from 15.8 to 32 Mt).

The application scope of schemes for opening and development of coal open-mine fields by applying the modular integrated mining-technological structure embraces practically all the range of conditions at many-years operating, new-designed and perspective open mines on flat-lying coal seams in Kuzbass. It is of specific importance for mining at underground areas of the first order specified with the critical overburden ratio; as the operation life of a coal mine can be notably extended with no appreciable investments and properly-minded subsoil management. It is reasonable to use the integrated mining technology to drain openpit fields at coal deposits with complex hydrogeological conditions; it can be efficient at coal open cast sections where integration of mining and drainage operations is imperative. In 2017 12 coal mining entities applied the integrated mining technology and yielded approximately one forth of coal production in Kuzbass.

![Figure 2. Structure of coal production by the integrated mining process in Kuzbass, thousand tons per year.](image)

Performance of the integrated mining process is higher thanks to a number of factors:
— combined use of available production infrastructure, power lines, auto- and railway lines, substations, moto-transport fleet to handle coal, etc.;
— handling of opencast coal at conveyors of underground section of the mine, thus optimizing the transportation performance;
— use of opencast machinery in view to lower labour intensity in overburden removal in order to open coal seams for underground mining;
— drainage of the production seam thickness within the opencast mine field;
— opportunity to arrange internal dumps after the open mining operations are cancelled to provide rational extraction of coal seams within a coal mining lease.

For period from 2006 to 2017 the researchers of Institute of Coal developed technical solutions on the integrated geotechnology for comprehensive coal resource utilization, protected by 15 RF Patents. This factor is of prime significance in view to protect innovations concerning the concept “Intellectual mine at a coal opencast” in Russia.

It is important that the integrated coal seam mining can be realized based on a production block (a module) [9].
At the Institute of Coal SB RAS under development is the methodical approach to the consecutive formation of mining technological models and their optimization based on the all-round analytical data. In 2017 the principal parameters of the integrated coal mining geotechnology: production cost, price, profit, profitability were analyzed by using the methodology for evaluation and selection of effective technological schemes of coal seam mining under actual mining and geological conditions at Kuzbass operating collieries. Economic and financial parameters are reported for 12 Kuzbass mining entities with total coal production of 59,424 thou t of coking coal brands in the Table. The cost of coal production by the integrated mining technique is averaged and equals 2286 Rub/t, coal price being 3513 Rub/t [10]. Profitability of marketed products estimated as a ratio of balance profit to current expenditures amounts to 45%, profitability in terms of net profit is 39%.

Table 1. Economic and financial parameters of coal production by the integrated mining technique in 2017.

| Parameter | Value |
|-----------|-------|
| Marketable coal production by open/underground mining technique, total, thou t: | |
| Open mining | 59424 |
| Underground mining | 35005 |
| 27419 |
| Expenses on marketable product production, MRub | 135843 |
| Production cost of 1t of coal, Rub | 2286 |
| Price of 1 t of coal, Rub | 3513 |
| Marketable product, MRub | 208755 |
| Production profits, MRub | 72912 |
| Property tax, etc., MRub | 11819 |
| Pre-tax profit, MRub | 61093 |
| Profit tax, MRub | 15273 |
| Net profit, MRub | 45820 |
| Net profit, Rub/t | 771 |
| Profits margin, % | 45 |

3. Conclusions
At Institute of Coal SB RAS the modular mining-technological structures of mine sections, adapted to the integrated coal mining technique in Kuzbass are developed and protected by Russian Federation Patents. These intangible assets are of specific value for business oriented to research work and commercialization of intellectual products. Intellectual property can be considered as a perspective credit instrument in the scope of scientific concept “intellectual mine at a coal opencast”. High performance of the integrated technique to mine coal seams is established, the profitability exceeds 1.5 times the average profit value in Kuzbass.

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