

Longwall top coal caving (LTCC) mining technologies with roof softening by hydraulic fracturing method

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Abstract. The paper discusses advanced top coal caving technologies for thick coal seams and addresses some issues of incomplete coal extraction, which can result in the environmental damage, landscape change, air and water pollution and endogenous fires. The authors put forward a fundamentally new, having no equivalent and ecology-friendly method to difficult-to-cave roof coal – directional hydraulic fracturing and nonexplosive disintegration.

1. Introduction

Most countries in the world produce coal using high-output fully mechanized longwall mining technology (round 84% of total coal production). Sustainable efficiency of such mines requires maintaining all-time high output per face (more than 4 thousand tons per day), which is only possible in favourable ground conditions [1]. The effective range of the fully mechanized longwall systems can be expanded by means of cutting difficult-to-cave roof strata. Under such conditions, unexpected and uncontrollable rock falls are highly probable, which is extremely dangerous to mine personnel, mining equipment and roadways. Furthermore, overhanging roof induces concentrated rock pressure in production face area and its junctures with roadways, which can trigger coal and gas outbursts.

In rockburst-hazardous and outburst-hazardous coal mining, overhanging difficult-to-cave roof increases stresses on coal face edges, which provokes dynamic and gas-dynamic events. At the moment of roof caving, gas releases from fallen roof rocks in roadways, which violently increases methane content of mine air. Gas bursts are accompanied with powerful shock waves and can induce rock failure or inflammation and explosion of gas and coal dust.

Many researchers address issues connected with thick coal strata mining.

Mondal D., Roy P.N.S. and Behera P.K. (Coal India Limited, Indian School of Mines) in the article “Use of correlation fractal dimension signatures for understanding the overlying strata dynamics in longwall coal mines” prove that longwall mining is considered to be the best coal mining practice due to vast recovery of coal over other forms of underground as well as opencast mining methods.

Duncan G., Sobey G. and Clarke T. (Austar Coal, DBT Australia) in their study “Top coal caving longwall maximizes thick seam recovery: Austar’s longwall system offers opportunities in seams thicker than 4.5 meters” share hands-on experience on the Longwall Top Coal Caving (LTCC) method used by Austar mine, owned and operated by Yancoal Australia, for extracting coal seams thicker than 4.5 m.

In the work “Three-dimensional experimental study of loose top-coal drawing law for longwall top-coal caving mining technology,” Jiachen Wang, Jinwang Zhang, Zhengyang Song and Zhaolong Li (China University of Mining and Technology) investigate the loose top-coal drawing



law of the longwall top coal caving (LTCC) mining technology using self-developed 3D test device based on the loose medium flow field theory.

According to the analysis of the coal resource base of the Russian Federation, in-place reserves of coal mines contain 1/3 of unfavorable and 1/10 of extremely unfavorable coal unsuitable for fully mechanized longwall mining technology. By expert estimates, not more than 1/3 of known coal reserves are suitable for fully mechanized longwall mining technology, which is an impeding factor to competitive ability of the coal mining industry in the world market, and 2/3 of high-quality coal occurs in steeply dipping seams. The difficult ground conditions are one of the sources of problems in the present-day mining. Thus, efficiency and ecological friendliness of coal mining is the top-priority objective in Russia, and the prospects of coal mining in the country depend on the success of reaching that objective.

2. Methods

Not all underground coal mining technologies are efficient and ecology-friendly. At the stage of mine planning and design, coal recovery rate is calculated based on the value of project coal loss, including irrecoverable loss of coal within mine fields. At the same time, coal recovery rate is in many ways governed by ground conditions, specifically, by thickness and dip angle of coal seams, by depth of mining and by mining technology. Incomplete extraction of coal may result in endogenous fires in mined-out areas, which is hazardous to health and tangibles. Landscape changes, air and water pollution, methane emission and other negative factors take place at the same time.

Coal mine safety rules state that mining of spontaneously inflammable coal should involve full-scale backfilling. Furthermore, in case of thick inflammable coal seams, it is required to make separate extraction panels with fire barriers in-between, which reduces coal recovery rate.

At this conjuncture, it is required to come up with an efficient process solution to ensure competitive ability of mines cutting thick coal seams.

The international practice of thick coal seam mining involves multi-slice working and one-slice longwall mining technologies. Multi-slice working causes high coal loss and, as a consequence, induces risk of endogenous fires. For this reason, the most preferred method is one-slice thick coal seam mining with top coal or interlayer coal caving [1].

There are two known scenarios of mechanizing longwall top (interlayer) coal caving method – using a front face conveyor, e.g. KTU and KNKM (manufactured in Russia) or VHP-731 (Hungary) and using a complete longwall armored rear face conveyor, e.g. OKPV-70 and KM81V system (Russia), or AFC (China). The latter variant has widely been introduced in China, where there are many thick and super thick coal seams and where high-productive coal mines reach annual coal output of 4.5–8.00 million tons with one or two operating longwalls. Different types of powered roof support connected with the features of longwall mining technologies have been successfully trialed in Yangzhou, Yangquan, Luan and Datong [2, 3].

The advantages of top (interlayer) coal caving with the complete longwall armored face conveyor include appreciable reduction in preparatory works, in capital and operating costs, power consumption and in spontaneous inflammation of coal; moreover, it allows coal mining in difficult ground conditions and enables extracting coal left in pillars. All these benefits enhance efficiency and safety of mining at the increased output per face and higher mining rate.

The new technology proposed for thick coal seams is implemented with the help of mechanized systems with robotic coal discharge using feeders with adjustable capacity [4, 5]. The design of the powered roof support with the controllable coal discharge to face conveyor takes into account geomechanical processes running in coal and roof rocks, involves advantages of the similar known designs and eliminates their shortcomings. This offers a new vision of advancement in the science-based technologies of thick coal seams longwall mining

The proposed technology enables one-slice cutting of coal seam 8.0–10.0 m thick at the coal recovery rate of not less than 0.8 and the projected output per face up to 15 thousand tons per day.

A similar approach is intended to be used in underground mining of thick steeply dipping coal seams with sublevel caving method.

The domestic industry currently does not manufacture high-capacity longwall systems suitable for efficient and safe mining of thick steeply dipping coal seams. Thus, thick steeply dipping coal is not extracted using underground mining methods because of the lack of appropriate mining machines.

One more competitive advantage of the recommended technology is its applicability in thick steeply and super steeply dipping coal seams using travelling powered shield support.

The proposed technologies avoid drilling-and-blasting but involve a new, having no equivalent approach to difficult-to-cave roof—method of directional hydraulic fracturing.

The currently available techniques of softening difficult-to-cave roof coal (advance torpedoing, hydromicrotorpedoing, etc.), despite the many years-long experience, are not always efficient for a few common drawbacks – non-uniformity and uncontrollability of rock breakage. The proposed method of directional hydraulic fracturing (DHF) integrates lamination and separation of rocks per blocks, which avoids roof overhanging and eliminates abrupt dynamic events in the time of immediate and subsequent bents, allows more uniform change in mechanical properties of rocks and ensures safety in reused roadways. A dedicated equipment set has been designed and tested in mines. Based on the multiple experimentation on application of DHF to softening roof rocks in assembling rooms in mines, as well as on the ground of visual observations, figure 1 shows a schematic pattern of roof caving when the fully mechanized longwall system comes out of an assembling room.

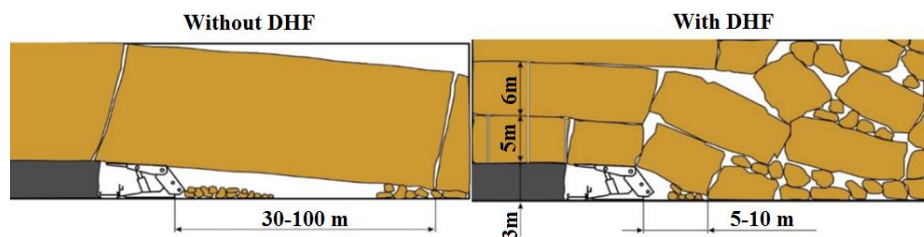


Figure 1. Cutting of difficult-to-cave roof with and without softening by DHF.

3. Results and discussion

The full-scale practice shows that lamination of hard solid roof rocks not only offers comfortable working conditions for powered support and cutter-loaders but enables preventing such dynamic events as rock bursts and coal and gas outbursts. Currently, the described approach is widely introduced in Kuzbass mines in Russia [6] and is included by Polish practitioners in Pokoj Mine in various process flowsheets as the basic procedure to prevent rock bursts [7].

Pre-mining methane drainage faces some technical difficulties as there is no developed network of drainage surfaces and channels before mining is started. The available degassing techniques allow recovery from 20 to 30% of total methane released. Because of this inefficiency of the current drainage technologies, many mines operating in coal seams featuring high gas content in Russia set a gas content limit, which hinders reaching high mining rate and high output per face. Thus, there is a paradoxical situation in the coal mining industry: the technical capability is available but unimplementable. This is also the explanation of low efficiency of labor and high injury rate. In the meanwhile, the modern strategy of underground coal mining anticipates high concentration and intensification of mining.

Aimed to enhance efficiency of pre-mining gas drainage in unloaded coal seams and for current degassing of coal after pressure relief, a fundamentally new approach to reaching maximum well rate has been developed—multiple directional hydraulic fracturing in a degassing hole (figure 2) [8].

The method consists in creation of long highly permeable drainage channels in the vicinity of a hole by means of opening of natural joints when new fractures grow. In this case, the cumulative methane content reduction in mine air in the operating zone of a cutter-loader is higher than in the

conventional degassing method, and the implementation period is 3–4 times shorter at the complementary effect of decreased dust content.

To this effect, the process flowsheets are developed and the full-scale equipment system of DHF has been designed and tested in mines.

The accomplished research and development make the framework for the technology that ensures reduction in the degassing drilling by 3 times and more at the simultaneous increase in the rate and depth of drainage not less than by 2 times at the final air-and-methane mix recovery. As a result, safety of coal mining is enhanced due to pre-drainage, risk of methane outbursts and rockburst hazard is mitigated owing to partial stress relief in rock mass due to fracturing, and harmful methane emission is reduced.

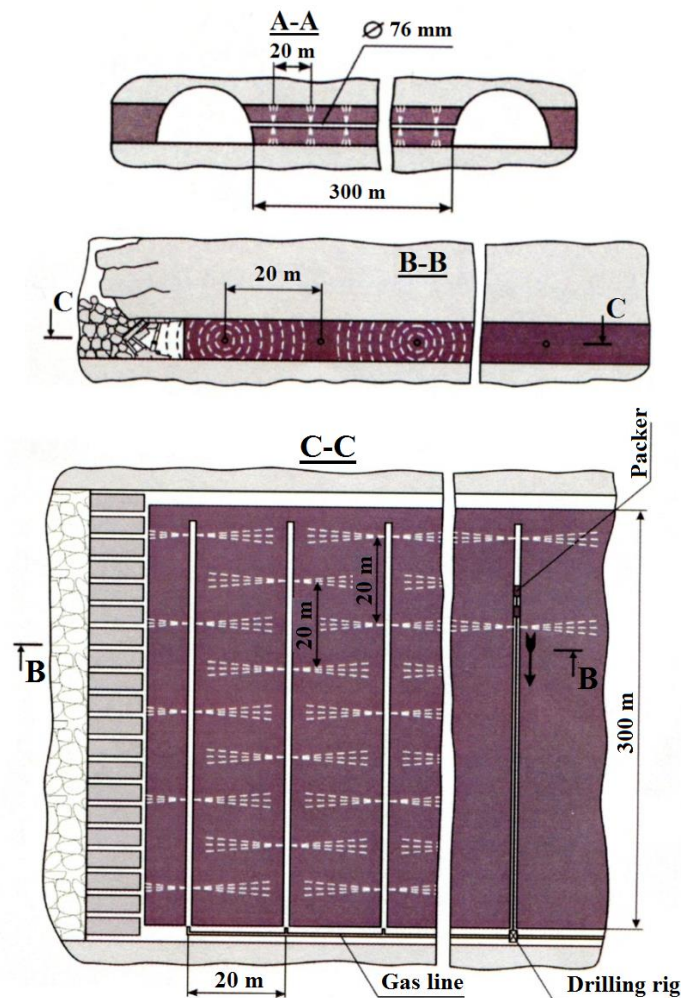


Figure 2. Multiple hydraulic fracturing pattern.

4. Conclusions

One of the key influences on the efficiency of the described longwall mining system and technology are the thickness of coal seams and breakability of coal under effect of rock pressure. The present paper authors put forward a thick top coal caving technology using the modern powered roof support with the controllable coal discharge. The fully mechanized longwall system design involves feeders arranged in the powered support units to ensure adjustable coal discharge along the whole length of the longwall, which enables enhanced economic performance of longwalling.

Parameters of powered roof support are inter-dependent and governed by process steps of advance of the powered support units; a rational travel step is selected with regard to the width of discharged coal flow, divisible by the total number of the powered roof support advance steps, or to the width of longwall. The both designs of powered roof support for cutting thick coal seams with the controllable discharge to front or rear armored face conveyor offer new prospects for thick coal seam mining using underground methods. The potential advantages include:

- one-slice longwalling, which promotes high concentration of mining, reduces production loss and abates risk of endogenous fires;
- reduction in volume and cost of development heading and maintenance by 1.5–2.0 times;
- utilization of rock pressure and cavability of top coal, which cuts down coal production cost;
- decrease in cost of longwall equipment and coal haulage within a mine field;
- decline in value of assembling and disassembling of longwall systems, haulage machines, electric equipment, pipelines, preventive control, etc;
- saving of cost of produced coal at the concurrent sharp increase in output per face given relatively slight growth in manpower.

The proposed technologies are meant for the coal producing regions in Russia, India, Georgia and other countries engaged in mining of thick coal seams. On the other hands, subject to relevant modification, these technologies are adaptable to thick salt rock beds and diamond-bearing strata.

Acknowledgements

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