

EFFICIENCY OF TECHNOLOGIES OF INTENSIVE METHANE RECOVERY FROM COAL SEAMS AND MINES PROPOSED FOR CLOSING

A.D. Ruban, Corresponding Member of the RAS
V.S. Zaboruyaev, Dr.Sc.(Tech)
G.S. Zaboruyaev, Dr.Sc.(Tech)
(National Mining Research Center –
Skochinsky Institute of Mining,
Lyubertsy, Russia)

Coal enterprises have always been and unfortunately remain high hazard operations. The hazard increases by many times in high gas volume mines where explosions of methane-air mixtures or, what is even worse, methane-dust-air mixtures can occur and cause accidents, namely, death of many miners, partial or complete breakdown of the mine because of important failures and underground fires preventing from victims bodies taking out to the surface. In addition to high hazard underground mining of methane-bearing coal deposits is associated with abundant methane and dust emissions mostly vented to the atmosphere and thus, polluting air, water bodies and vegetation. In this context, it is necessary to improve the existing technologies of methane recovery and to develop new more efficient processes, and to make arrangements so as to prepare coal seams for safe and highly productive mining.

New technologies of intensive methane recovery from coal seams being under rock pressure can be divided into 3 main groups:

- technology of seam degassing with crossing holes in breakage districts [1-6];
- technology of degassing with preliminary hydroimpulsive stimulation of coal massif to improve its permeability and gas recovery [7-10];
- technology of thick seam degassing when driving mine workings that includes hydraulic breakage of coal massif through the hole drilled in advance to the mine face. This hole communicates through artificially induced fractures with barrier holes drilled second to it and the holes of preliminary degassing drilled in advance in the lower part of the seam [3, 5].

The method of seam degassing by crossing holes is based on the effect of coal massif unloading near the holes cavities in their junction points where two systems of vertical crossing holes are formed. The cracks induced provide aerodynamic communication between the series of holes drilled at an angle to each other. As a consequence, coal massif is more uniformly degassed, the disturbances of vacuum link between the degassing system and individual boreholes or their parts (when blocks are formed in water-bearing seams) are excluded or reduced to a minimum. In the influence zone of the breakage face crossing holes intensively develop that contributes to even higher degree of coal massif degassing. At the same time, methane released in the area being unloaded is taken from the face to the degassing system. To improve the

aerodynamic link between the systems of crossing holes artificial bed stimulation is used, for instance, hydraulic fracturing of the massif. The bed stimulation is most advisable for thick seams and on mine workings driving, if the time assigned for degassing of the massif is limited.

The method of degassing by crossing holes that includes drilling from a mine working of a series of face-oriented and parallel to the face holes is efficient and simple to realize. And degassing of the mining field being developed by drilling crossing holes beyond the contour of the future development working is preferable.

It is advisable to use degassing schemes with crossing holes in high gas content and prone to outbursts seams. At delineated mining fields the holes drilled parallel to the breakage face should be by 10-15 m shorter than length of the face. At a non-delineated mining field the degassing holes are drilled at least 5 m beyond the outer boundary of the mine working being driven. The diameter of a hole is 76 mm. The angle of turn of face-oriented holes is 50-65°. The distance between the clusters of crossing holes depends on the required degree of the seam degassing and its gas yield. The time of preliminary degassing of the seam beyond the influence zone of the face is at least 6 months. The coefficient of seam degassing (level of gas emission reduction) is 0.3-0.4 for 16 m distance between the series of holes (clusters) and 0.4-0.5 for 12 m distance between them. In seams with uneven hypsometry the holes are drilled from conveyer and ventilation workings. Crossing holes in mining fields provide not only highly efficient degassing, but also contribute to deeper wetting of the coal massif.

The figures of methane recovery from natural coal seams by crossing holes and by parallel-single holes are given in Table 1.

The methods of degassing with preliminary hydroimpulsive stimulation of coal massif are used in natural coal seams with low gas permeability and gas yield. As the methods of hydraulic fracture of seams through the holes with static conditions of fluid pumping used in practice cannot produce a ramified fracturing pattern in the massif, the solutions have been proposed that allow to efficiently stimulate the seams occurring at different depths from the surface.

The essence of new methods of hydraulic treatment of seams consists in that the hydraulic treatment is made in a pulse mode in two successive stages. At the first stage a network of large fractures is created and at the second stage large cracks are divided into a system of small cracks.

To implement this method a new engineering solution has been suggested [7] allowing to obtain the required rate of pulse pressure rise, the parameters and conditions of stimulation of massifs with different physico-mechanical properties. The method and the device can be used to form fractures in natural seams for efficient application of degassing in mining fields, outburst hazard seams and on mine workings driving when a fracturing pattern should be

Table 1

Comparison of methane recovery from natural coal seams using new
(Scheme 2) and traditional (Scheme 1) technology of degassing

Mine	Face	Average depth of mining, m	Seam degassing by parallel-single (Scheme 1) ? crossing holes (Scheme 2)	Time of seam degassing, days	Specific quantity of methane recovered through holes, m ³ /m	Reserves of dry ash-free coal degassed through the hole, t/m	Quantity of methane recovered through the hole per 1 t of ash-free coal, m ³ /t	Growth coefficient of specific volumes of methane captured at equal drilling volumes
Karaganda basin								
«K.O.Gorbachev»	152K _{1-z}	450	Scheme 1	300	75	50.0	1.5	1
			Scheme 2	300	165	43.4	3.8	2.2
«Sokurskaya»	51K _{7-v}	520	Scheme 1	360	34	68.0	0.5	1
			Scheme 2	360	95	25.7	3.7	2.8
	54K _{7-v}	520	Scheme 1	155	57	114.0	0.5	1
			Scheme 2	145	99	18.7	5.3	1.7
«50 years of the USSR»	37K _{12-1v}	360	Scheme 1	330	53	84.6	0.6	1
	35K _{12-1v}	360	Scheme 2	330	129	44.0	2.9	2.5
Donetsk basin								
«A.F.Zasyadko»	5 th western face in the seam I ₁	820	Scheme 1	Degassing in the influence zone of the face	38	31.7	1.2	1
			Scheme 2		73	31.7	2.3	1.9
«Krasnokutskaya»	23rd northern face in the seam I ₆	200	Scheme 1	120	22	20.0	1.1	1
			Scheme 2	120	24	16.0	1.5	1.1
Jiaozuo Basin (the PRC)								
«Julishan»	13051 (seam II ₁)	245	Scheme 1	150	49	32.7	1.5	1
			Scheme 2	150	130	52.1	2.5	2.7

formed between holes, and also to enhance gas recovery from overmined seams.

As the seams with different penetration and gas yield have different limit radius of drainage when opened with a hole (3.6 m in Kuzbass, 3.2 m in Donbass and 4.4 m in Karaganda basin, on average) to provide efficient degassing of natural seams, in particular, outburst hazard ones, it is necessary to artificially form in the seam a network of fractures with an interval equal to the double radius of drainage. This requirement is most topical for regional treatment of seams (degassing and wetting), for driving mine workings under conditions of insignificant unloading effect of the face, as well as for opening and degassing of outburst hazard areas of known location. In these cases the methods and means of hydroimpulsive fracturing can be applied. As energy carrier both solid blastless matters (when a pulse device with energy carrier is placed in the mine working) and liquid substances (that fill the hole) are used.

New engineering solutions have been theoretically substantiated and experimentally or bench or field tested at mines in Kuznetsk, Donetsk and Karaganda coal basins. The results of investigations in the field of intensive degassing of coal seams have been summarized and used as a basis for the development new schemes of degassing some of which became standard.

General schemes of natural seams degassing by holes with preliminary hydroimpulsive simulation of the massif are used in gas-bearing seams with low gas-permeability and gas yield both in static and pulse modes of fluid pumping. The methods, means and parameters of hydroimpulsive action on the seam and the schemes and parameters of the seam degassing are determined according to the recommendations issued by the National Mining Research Center-Skochinsky Institute of Mining based on the data on gas-dynamic state of the seam, its gas recovery into the holes, the limit radius of drainage, and also taking into account mining conditions of the seam to be degassed.

To implement the required parameters of the seam treatment a hydroimpulsive unit has been developed [7] that uses as energy carrier the charges of ballistic solid fuels which release energy on their conversion during the stable burning process. Consequently, a mixture of gases is produced the main components of which are N_2 , CO_2 , CO and H_2 . The rate of pressure rise in the pulse, the value and time of the pressure pulse action are adjusted by varying gas inflow through selection of the mass and shape of the charge (design and geometry), fuel grade, its energy and ballistic characteristics.

To determine the initial properties and the design of solid fuel charge there has been developed a mathematical model describing the process of the charge burning and gases discharge from the combustion chamber to the shaft. The method allows to calculate the main operating parameters of the unit: combustion products pressure, temperature, fluid consumption through the shaft of the impulsive unit, fluid speed in the shaft. Operating parameters of the unit have been tested on a bench with three different design options of uniformly burning charges:

option 1 – a charge of variable length consisting of seven single channel blocks with outer diameter of 60 mm and the channel diameter of 12 mm;

option 2 – a charge of variable length consisting of a single channel block with outer diameter of 180 mm and the channel diameter of 30 mm;

option 3 – a charge of variable length consisting of a single channel-free block with outer diameter of 180 mm.

The relation between the velocity of liquid in the pipe with dies that simulates the hole and the massif and the time have a form of splashes of different amplitude separated by pauses. The velocity of liquid in the pulse substantially exceeds the required value of 28.3 m/s (liquid consumption of 100 l/s).

The performance of the hydroimpulsive unit with solid fuel charges of different design (options 1-3) is shown in Table 2.

The behaviour of pressure in the combustion chamber depends to a great extent on the value of the initial combustion surface of the charge: the larger is this surface, the more dynamic is the fluid effect on the coal seam and the shorter is the vibratory process in the combustion chamber. The charge consisting of seven single-channel blocks meets the main requirements of pulse treatment of the coal seam at minimum mass of the charge.

Table 2

Results of bench testing of the unit

Charge design	Charge mass, kg	Max. gas pressure, MP?	Time to achieve maximum pressure, s	Average gradient of pressure rise, MP?/s	Burning time of charge, s	Time of impulse, s	Shift of «gas-liquid» interface, m
Option 1	5.353	61.89	0.200	309.45	0.430	0.459	14.816
Option 2	9.360	54.02	0.250	216.08	1.351	1.372	13.996
Option 3	13.110	57.79	0.192	300.98	3.245	3.245	14.613

The hydroimpulsive stimulation of a coal seam with the view of forming a ramified network of artificial fractures favors both higher gas recovery from the seam into degassing holes and deeper subsequent wetting of coal through the same degassing holes. Complex treatment of coal massif so as to prepare it for highly productive and safe mining as regards to gas and dust factors contributes to higher (up to 40-50%) efficiency of the seam degassing and lower dust production (up to 80-90%) on mining machine operation. The highest figures are achieved when crossing holes are used. It has been found that a decrease of methane content x of the seam leads to lower concentration of most dangerous dust fraction (under 70μ) in broken coal γ_{seam} . This relationship, for instance, at Vorkuta deposit, is described by the following formula

$$\gamma_{seam} = 0.128x + 0.8.$$

Thus, the application of new technology of coal seams treatment through holes in advance to breakage operations allows to reduce methane emission to

the working area by 1.5-2 times and dust production during coal extraction by the shearer by 1.5-1.6 times.

For Russia are also topical the problems of methane recovery from mines proposed for closing. On mine closing methane emission into abandoned mine workings and worked-out areas of abandoned faces continues. Methane can rise through technogenic fractures to the surface creating hazard for people and installations located in the territory of the closed mine. Hazard appears as ignition of methane-air mixtures or people poisoning with gases in non-ventilated basements.

In the Russian Federation 175 very unprofitable mines were closed, including 30 high methane volume ones which by the time of closing were emitting the following volumes of methane: in Kuznetsk basin - 10-130 m³/min, in Vorkuta - 40-100 m³/min, in Eastern Donbass - 10-55 m³/min, and in Chelyabinsk basin, Primorye and Sakhalin –10-20 m³/min.

The planned schedule of mines closing provided for a pre-liquidation period during which the project of the mine closing was developed and approved and a period of technical liquidation of the mine and the final period of elimination of harmful consequences of mining operations (reclamation).

The carried out research resulted in the following:

- a model of methane emission under conditions of a closed mine was developed taking into account a) the relationship between the rate of decrease of coal production at the mine and the rate of reduction of mine methane volume in the final period of mine operation and coal mining, and b) the process of methane volume decrease with time after stoppage of breakage operations at the mine;

- time dependencies were found for the absolute average daily coal production at the mine and the intensity of methane emission from the mine before and after stoppage of mining coal and relative values of these parameters were determined using the relations of current values to maximum values;

- a model of methane emission in the mining district was adjusted. This model qualitatively describes the process of variation of methane emission intensity in the area in different periods: 1) before breakage operations, when methane is mainly emitted from the seam being mined; 2) on the first caving of main roof, when methane emission in the district achieves its maximum level; 3) during stable operation of the face; 4) on coal mining reduction, when methane volume of the area decreases from the maximum to the residual value to the moment of stoppage of breakage operations; 5) after stoppage of mining in the face, when methane is mainly emitted out of goaf and reduction of methane emission with time is observed.

The methods of carrying out work included gathering, processing and analysis of the data on the average daily coal output and methane volume variation with time both before and after stoppage of mining in accordance with the model of methane emission, as well as summarizing of actual, archival and published documents relative to the evaluation of environmental danger associated with methane emission from coal mines. In addition, it was envisaged

to determine gas yield from the coal seams being mined and adjacent seams into mine workings and degassing holes taking into account methane content variation with depth and dependent on location of the upper boundary of the methane zone within the field of the mine proposed for closing.

As a result of the investigations performed with reference to the mines proposed for closure the following was found.

High gas content and the presence of undermined and overmined adjacent seams caused highly intensive gas emission into mine workings in the mining districts and at the mine as a whole. In case of substantial decrease of average daily coal output and insignificant increase of mining depth methane volume of mine increased showing the essential role of methane content growth coefficient in coal seams with depth.

The linear character of decrease of average daily coal output in the pre-liquidation period of the mine was associated with linear dependence of methane content decrease with time at a rate that was much lower than the rate of decrease of average daily coal output. It shows that the worked out area was intensively supplied with methane emitted primarily by adjacent coal seams and gas-bearing rocks.

The resources of methane present in the goaf of the abandoned face are found as the difference between the volumes of methane emitted from adjacent coal seams and rocks and those recovered by degassing/gas suction facilities and carried away with ventilation currents.

The intensity of methane emission both in the ventilation network of the district and in the goaf sharply increased with breakage development and coal output growth. The intensive methane emission in the district was registered even after coal output had decreased. It can be attributed to the continued extension of unloading area of roof and floor rocks where adjacent seams were present. The period of unloading of adjacent coal seams lasted 3-4 months. On completion of the process of the roof and floor rocks unloading the period of natural gas emission from coal seams began.

The observed data and calculated dependencies of methane emission dynamics in the districts proposed for closure confirmed, first, the accuracy of adopted methodical approach to the study of the processes of methane emission in mining districts from the beginning to the end of their operation; second, the need in the analysis of the actual state and initial data for evaluation of volumes and intensity of methane emission in the district being studied; and third, scientific validity of the existence of real methane resources in each specific case and the possibility of their recovery and utilization.

The volumes of methane emission in the mining district during breakage operations and after their completion are far from being comparable. On implementing the measures of methane recovery the gap between the processes of methane recovery during coal face operation and in the subsequent periods when rocks unloading in the influence zone of breakage operations continues is inadmissible.

The difference between the values of methane accumulation and methane emission in the specific period of time is that of methane resources contained in the goaf. Specific methane resources in the goaf amount to 1.9-2.0 m³/m³ of goaf.

On planning degassing of the mines proposed for closure and choosing engineering solutions as to the methods, conditions and parameters of recovery of methane suitable for utilization it is necessary to follow the provisions of the normative document on coal mines degassing. As a rational scheme of methane recovery it is recommended to use the one that includes drilling and utilization of boreholes drilled in advance from the surface into the goaf of the face and a mobile degassing unit capable of recovering under optimal operating conditions qualified gas-air mixtures as to methane content. These mixtures with methane content of 30% and over can be burnt in the mini-power stations with up to 1000 kW capacity and other units intended for the recovered methane utilization.

The technology of degassing and operating the units for recovery and utilization of methane from the Russian coal mines proposed for closure should be realized in accordance with the requirements of the normative guide on degassing coal mines of Russia and operating instructions.

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