Complex Technology of Underground Coal Gasification and Coal-Based Methane Recovery Using Geodynamic Zoning

Shabarov Arkady Nikolaevich
Saint-Petersburg Mining University
Vice-Rector (Head) of Center of Geomechanics and Issues of Mining Industry, Doctor of Engineering Science
2, 21 line, Vasilievsky Island, Saint-Petersburg, 199106;
tel: (812) 321-9609
post@spmi.ru

Tsirel Sergey Vadimovich
National Mineral Resources University (Mining University)
Chief Research Fellow, Doctor of Engineering Science
tsirel58@mail.ru

Goncharov Evgeniy Vladimirovich
National Mineral Resources University (Mining University)
Senior Research Fellow of Laboratory of Geodynamics
goncharovbox@mail.ru

Abstract:

The article describes the complex technology of coal methane recovery, which involves underground coal gasification of lower beds in series of gas-rich strata liable to rock-bumps, coal based methane recovery and mechanized coal mining. Geodynamic zoning is used for selection of places for well drilling.

The application of the suggested technology enables to solve a range of tasks, such as

- unloading of workable beds and reduction of their rock-bump hazard due to protective seam burnout;
- increase of workable beds degasification due to unloading;
- increase of workable bed methane desorption rate due to conductive and partly convectional heat transfer through interbeds;
- reduction of workable bed coal strength and rock-bump hazard by passing-through combustion gases (CO and especially CO_2);
- degasification of coal bearing layers and sublayers of interbeds due to their partial burnout during gasification and accelerated degassing during intensive heating;
- increase of gasification products heat value due to their diluting with methane recovered from upper beds degasification;
- reduction of methane outburst to the atmosphere, which has greater greenhouse effect in comparison to carbon dioxide.

Key words: series of coal strata, gasification, complex technology, degassing, geodynamic zoning, methane.

The significant amount of ultimate coal reserves is located in the series of gas-bearing strata liable to rock-bumps and could not be recovered with conventional mining methods. During ascending exploitation mining the extraction of coal from the lowest seam is quite challenging or impossible due to high geodynamic risks. During descending mining the overworking has low impact on processes of

V. Litvinenko (ed.), *XVIII International Coal Preparation Congress*,
DOI 10.1007/978-3-319-40943-6_77

unloading and gas emission from lower beds, thus mining can be done only up to the first thick interbed or until reaching very hazardous beds.

The conventional method of mining series of strata prone to rock- or outbursts involves initial extraction of protective seam. [1, 2]. The advantages of this method are parallel extraction of protective and main seams during the period of the highest unloading and its maximum effect due to relatively small advances.

However, firstly, when mining methane rich coal beds the extraction of protective seam using oil mining becomes highly risky in every aspect – outbursts, rock-bumps, intensive gas emission, and methane explosion risk, which prevents protective seam extraction under extremely hazardous conditions at great depths.

Secondly, the non-pillar extraction is quite challenging within the framework of conventional mining methods, and if there are difficult conditions in the protective layer, the mining process could not be carried out at all. The alternative to non-pillar extraction is creation of yield (long-holed) pillars, but even they cause high-pressure zones in the overlying beds though not very intense. Besides it is very challenging to provide yielding property of pillars created not for technical purposes (between extraction columns, panels, etc.), but for passing extremely hazardous tectonic disturbances (faults, flexures, folds) and formation morphological damages (swelly, balk, sandstone inclusion, offset, fault wash, etc). These pillars can be large in size, have complex shapes, rapid changing physical-mechanical properties, and produce significant burst (stress) pressure on joint coal seams.

Thirdly, the unloading of a hazardous seam due to extraction of protective layer only partially solves the issue of its degassing and increases gas recovery factor by reducing rock pressure. Moreover, the extraction of protective layer using conventional mining methods leads to intake of additional gas through interbeds, as well as from development and working faces during mining and later from worked-out areas. The gas from goafs may come not only from “fast sources” (not-mined layers of the face, rocks of immediate mine roof) but from “slow sources” as well (incomplete long-holed pillars, pillars around extraction column, zones of geological faults, off-spec coal bearing seams, sublayers and interbeds).

We consider underground gasification of protective layer to be the most advanced method. It was first studied in publications [3-5], several suggestions for developing this method were given in [6-8] and other papers.

In this paper the underground gasification of lower protective layer in series of strata is described not only as a method of unloading and reduction of rock- or outbursts hazard during overlying beds mining, but as a method of highly dynamic intensification of overlying beds degassing and methane recovery and more complete extraction of energy from coal-based methane deposits.

The complex technology combining coal-based methane recovery and underground gasification of coal from lower beds in series of gas-rich strata liable to rock-bumps solves several tasks:

1. unloading of workable beds and reduction of their rock-bump hazard due to protective seam burnout;
2. increase of workable beds degasification efficiency due to unloading;
3. increase of workable bed methane desorption rate due to conductive and partly convectional heat transfer through interbeds;
4. reduction of workable bed coal strength and rock-bump hazard by passing-through combustion gases (CO and especially CO_2);
5. degasification of coal bearing layers and sublayers of interbeds due to their partial burnout during gasification and accelerated degassing during intensive heating;
6. increase of gasification products heat value due to their diluting with methane recovered from upper beds degasification;
7. reduction of methane outburst to the atmosphere, which has greater greenhouse effect in comparison to carbon dioxide.

One of the main arguments against using in-place gasification (it is similar to arguments against shale production) is pollution of ground waters, reservoirs and withdrawal points. The suggested technology reduces this type of risk since gasification occurs at great depth and bulk of water from burnout zone is pumped out with mine systems of degassing and drainage, which enables to perform water treatment process.

The experience of underground gasification [9-10] has shown that the technology is most efficient for coal seams having the following characteristics:

- seam lies at the depth from 30 to 800 m;
- seam has great thickness not less than 5 m;
- ash content should not exceed 45%;
- part of the seam undergoing the gasification should not have evident faults
- high seam permeability (≥ 0.1-0.5 mD).

The presented example intentionally does not have the second characteristic as it is economically profitable to use conventional methods for mining thick seams, it is suggested to use thin seams (from 0.5-0.7 to 1.5-2 m) as protective layers. In some cases, it is difficult to meet the 1st condition as well since the lower seam can lie at great depth of 1 km and more. The last characteristics are very difficult to follow since under conditions of vertical and horizontal stresses the deep seated seams liable to rock-bumps have massive structure and low permeability (~ 0.01 mD).

That is why the rational selection of the starting place for gasification is very significant. This place should be located in tectonically unloaded zone with excessive fissuring and preferably having low water and high methane contents. In other words, when using other mining methods, the gasification should start with the places most favorable for degassing.

The selection of tectonically unloaded sections is made using geodynamic zoning. The application of this method entails reconstruction of block structure of coal lease, creation of joint map of geodynamic and gasodynamic factors, calculation of stress inside and at the edges of blocks, and evaluation of filtering and collecting properties of the section using connection between stress state and permeability.

The example of selecting the places favorable for degassing or initiating in-place degasification is shown at figure 1.

The second stage involves drilling, this technology requires three types of wells: draught, gas drawoff in burn area and degassing in workable seam (fig. 2). With further advancement the functions of the wells are switched hence all of them are used as draught, gas drawoff or degassing ones. The experience has shown that it is more efficient to drill wells with relatively large diameter for installing tubes with relevant capacity for gas drought and draw off. The drill rigs are equipped with control units and gyroscopic inclinometers for precise drilling.

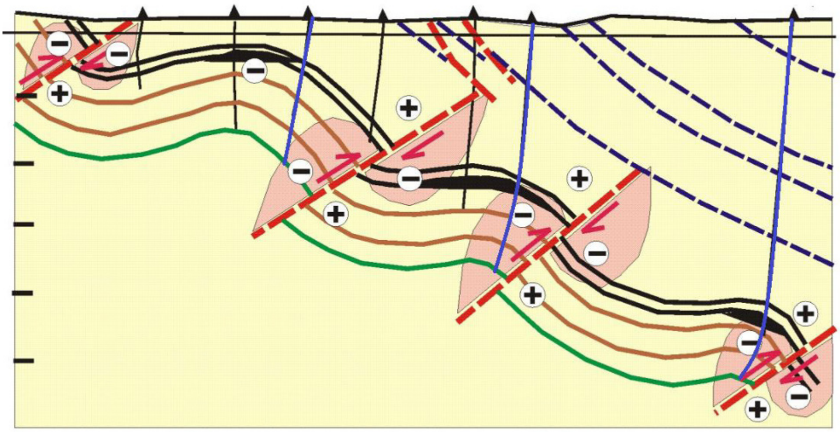

Figure 1 – Selection of places favorable for initiating degassing and underground gasification processes (based on materials of N.I. Mishin and A.L. Panfilov). The faults define stress condition of block structure and form compression and tension zones. The latter are the most favorable for degassing. The optimal positions of degassing wells are marked with black color, blue is used to show places for degassing and underground gasification of lower seam (green color).

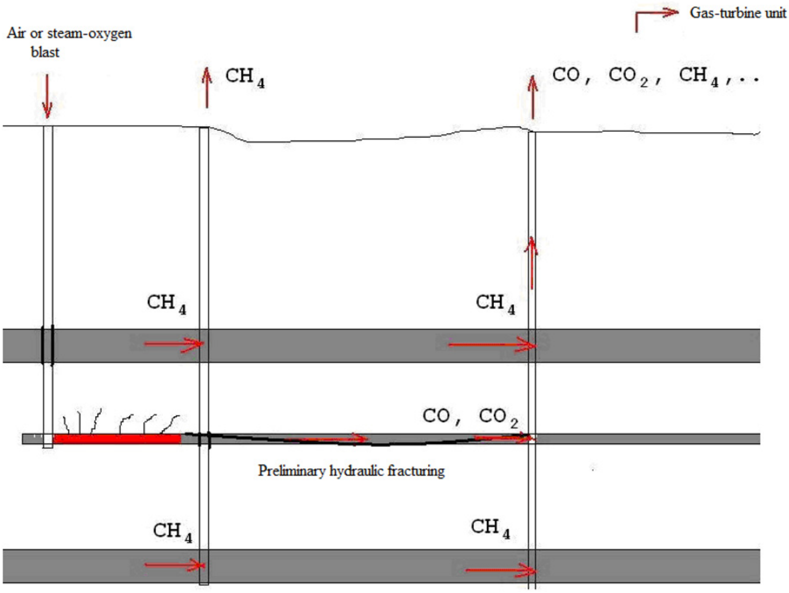

Figure 2 – Degassing by means of underground gasification of one of low thin beds.

The third stage involves creation of gas-permeable channels between draught and gas drawoff wells for preparation of underground gas generator and can be carried out using the following methods:

– linking of wells by burning filtering;
– hydraulic fracturing of coal seam with fluid or gas and burning of the created fracture (fig.2);
– drilling and burning of inclined and horizontal burn path.

The method selection depends on the existing mining and geological conditions and can be specified during design process. The temperature in the coal burning zone can be very low when there is a high water inflow to gasification area. The experience has shown that underground generator works efficiently with water flow up to 0,6 m^3 per 1 ton of gasified coal. Thus it is necessary to perform dewatering of the gasification place in case of high water flow in the gasified seam and/or when using hydraulic fracturing. The removal of water from the burn zone is done by permanent air injection under pressure exceeding underground water seam pressure.

The key element of the suggested technology is heating of interbed and working seams to increase degassing efficiency. In order to estimate the influence of heating process on methane desorption we can use experimental graph of I.L. Ettinger [11] for coal from Karaganda basin (fig.3) and empirical equation of G.D. Lidin [12]:

$$x_p = 65.5 \Big/ \left[V^{0,146} (a/P + b) \exp \frac{0.02t}{0.993 + 0.007P} (1 + 0.31\,W) \right] \quad (1)$$

where x_p – sorption methane retention capacity of coal, m^3/t, V – volatile content per combustible mass, %, P – pressure, atm, W – water content, %, a and b – coefficients depending on coal rank. It is important that dependency of sorption methane retention capacity of coal on temperature t (^oC) is quite general and similar for different mining-geological conditions, and temperature influences the process greater than pressure (depth of formation).

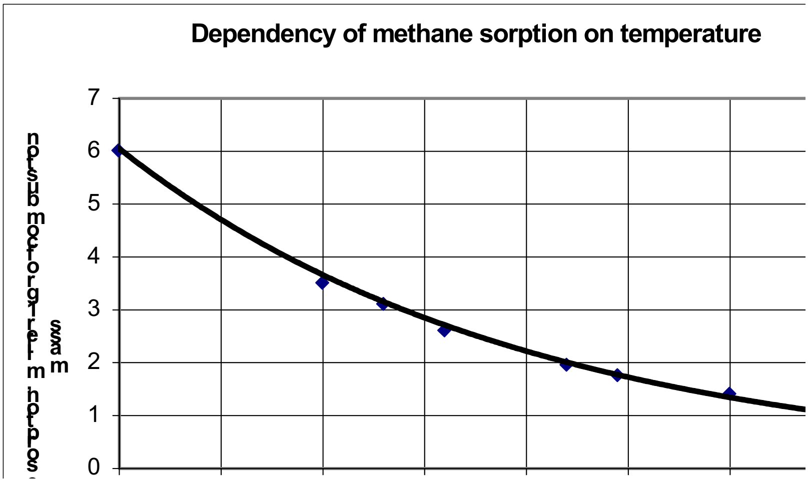

Figure 3 – Dependency of coal sorption capacity on temperature based on data [11]

For maximum heat transfer, on one hand, it is necessary to have the maximum possible combustion temperature. On the other hand, high speed of burning and pumping of coal-derived gas leads to reduction of heat amount transferred to enclosing rock. There is also a risk of burning a thick working bead if the interbed is thin.

On this basis we suggest three variants of underground gasification technology:

1. In case of thin interbed (up to 30-35 *m*, where *m* – produced seam thickness), it is recommended to use air blasting providing less rapid combustion. The air blasting could be used in case of low depth of production seam, thus heat loss will be relatively low and coal gasification paths will be formed in a more efficient way.

2. In case of thick interbed the risk of burning the working seam is quite low and it is more important to provide efficient heating. Thus the optimal solution is to use steam-oxygen blast providing higher burning temperatures (up to 800-1000 °C). At the same time the burning intensity should be kept at the minimal level supporting the stable process.

3. In case of over-thick interbed the direct heating of the working seam by heat transfer becomes very slow and inefficient. The produced gas could be used for additional heat impact on “seam-gas collector” through degassing wells. As shown on figure 4, in order to heat the thick seam and intensify degassing one or several wells were occasionally switched from withdrawal of combustion products to gas-turbine unit to passing through the seam. The combustion products CO and especially CO_2 facilitate coal strength reduction and accelerate methane desorption [13].

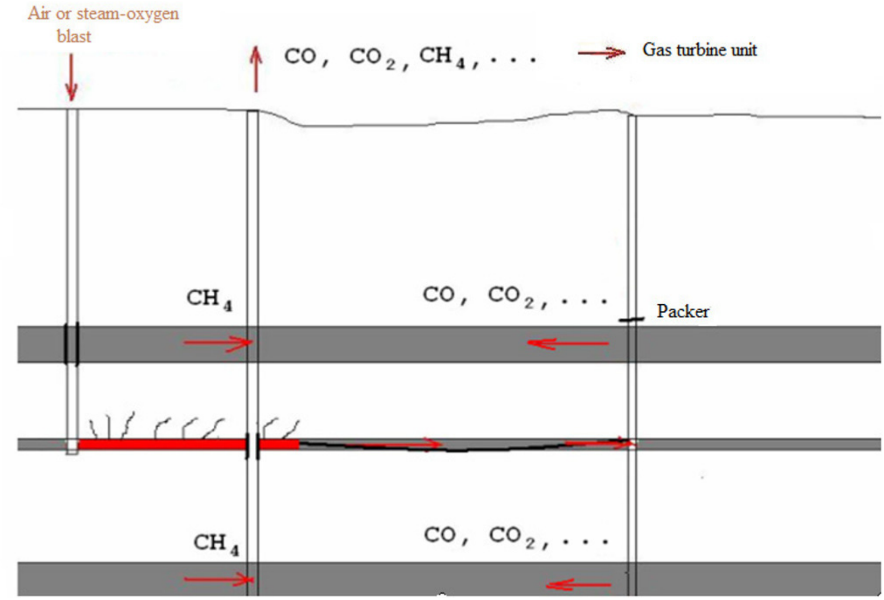

Figure 4 – Occasional intensification of degassing process by passing combustion products through seam

During gasification the burning intensity could become lower, especially in the zones of geological disturbances including minor faults and plication dislocations, balks, gaws, and seam inclination changes. In these cases, the intensification could be carried out by the inverse process – feeding recovered methane to combustion source. In order to stabilize and control the gasification process the authors of this paper developed and tested in laboratories and actual environment (Gas turbine unit at Angrenskaya plant) the techniques based on injecting liquid additives to expectable attenuation zones and squeezing them to the coal formation.

The gasification contours and volumes are monitored by the following:

- the volume of gaseous product;
- the results of observation over surface deformation;
- the control of burning face position using electro-magnetic survey methods developed by the authors of this paper.

The composition of the produced gas and its heating value are very dependent on type of combustion air and coal properties. When using air blow for gasification the produced gas has low heating value of about 4-5 MJ/m^3. This gas is suitable for gas turbine units producing electricity for drilling degassing wells, feeding power to compressors and pumps. When using steam-oxygen blast the produced gas has intermediate heating value of 10-13 MJ/m^3. The combination of gasification and degassing of working beds processes enables to produce the intermediate heating value gas by air blow and high heating value gas (from 20 MJ/m^3 and higher) by using steam-oxygen blast.

The underground gasification product generator gas used for production of heat and electric power also has valuable chemical raw materials: tar, phenol, hyposulphite, sulfur, etc. It is economically feasible to use chemical raw materials form gasification products recovered from condensate resulting from gas purification and cooling, including ammonia, phenols, tars, which can be extracted as saleable products (table 1). Depending on economic conditions the tar disposal can be done in two ways:

– total residue (mechanical additives and heavy tars – “heavy coal-tar products”) and coal are burnt in boilers;

– total residue is used in asphalt production for road construction.

Table 1 – Content of chemical components during underground gasification per 1 m^3 of product gas

Gasification products	Volume, g/m^3
Gas condensate	140-150
Ammonium	2,0-2,5
Benzene hydrocarbons	1,0-2,0
Tar	0,3-0,6
Pyridine bases	0,5-0,7
Sulfureted hydrogen	0,3
Tar camphor	0,1-0,9
Ethyne	0,003-0,1
Hydrocyanic acid	0,007

The purification of product gas shows that efficiency of separation of condensate from ammonium is about 98% in the form of aqua-ammonia 25% solution. After this process the phenols are captured from waste water in the form of sodium phenate. The dephenolized condensate is sent to bio-chemical purification and phenole purification degree is about 90%.

Thus the suggested technology will provide an opportunity to mine industrial coal reserves in series of gas-bearing strata liable to rock-bumps and complex usage of energy and chemical resources of coal-methane deposits.

References

1. Petukhov I. M., Linkov A. M., Sidorov V. S., Feldman I. A. Theory of protective seams. M.: Nedra, 1976. — 224 p.
2. Guidelines to efficient usage of protective seams in USSR mines. L., pub. VNIMI, 1970.- 105 p.
3. Kuznetsov V.P, Goncharov E.V. A. s. 949201 USSR, MKIZ E 21 F 5/00. Method of unloading and degassing of rock mass, 1980.
4. A. s. 1112128 USSR, MKIZ E 21 F 5/00. Method of development of gas-bearing coal deposits., // I.M. Petukhov, V. N. Kazak,. E.G. Goncharov and others. , 1983
5. Goncharov E.V. The possibility to use underground gasification for coal recovery from protective seams. // Ugol Ukrainy, 1990, N 2, P. 20-21.
6. Kapralov V.K., Kuznetsov A.A. Patent № 2122122, MKIZ E21F Method of development of gas-bearing coal seams, 1998.
7. Lazarenko S.N., Kravtsov P.V. New stage of underground gasification development in Russia and around the world. GIAB. 2007, № 6. – P.304-310.
8. Lazarenko S.N., Trizno S.K., Kravtsov P.V. Usage of modified technology of underground coal gasification for mining of gas-rich coal deposits. // Workshop materials № 17 of Moscow State Mining University “Development prospects of physical-chemical methods of mining” within the framework of symposium “Miner week 2010”. - M.: MSMU, 2010.
9. Underground gasification of coal seams, M., 1982.
10. Kreinin E.V., Pyankovo T.M. Prospects of production of natural gas alternative on the basis of the underground coal gasification // VNIIEGazprom, - M.: 1978. – 44 p.
11. Ettinger I.L. Gas retention capacity of mineral coal. M.: Nedra, 1966.
12. Lidin G.D. Mining. Encyclopedia, v.6. M.: Ugletekhizdat, 1959.
13. Dzhigrin A.V., Tkachenko N.F. Combined method of coal drawing with borehole charges and preliminary weakening of unworked coal by carbon dioxide. // Collection of articles “Blasting and nonreversible deformation of rock”. M., 1997. - P. 110-117.