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THE TECHNOLOGY OF EXTRACTING GASEOUS FUEL BASED ON COMPREHENSIVE IN SITU GASIFICATION AND COALBED DEGASSING

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The study considers a comprehensive technology (designed and patented by the authors) of developing coal and methane deposits which combines in situ gasification of lower coalbeds in the suite of rock bump hazardous gassy beds, extraction of coal methane and mechanized mining of coal. The first stage of the technology consists in mining gaseous fuel that enables one to extract up to 15-20 % of total energy from the suite of coalbeds. Geodynamic zoning is used to select positions for boring wells.

Using the suggested technology makes it possible to solve a number of tasks simultaneously. First of all that is extracting gaseous fuel from the suite of coalbeds without running any mining works while retaining principal coalbeds in the suite and preparing them for future processing (unloading and degassing).

During the first phase the methane-coal deposit works as a gas deposit only, the gas having two sources – extracted methane (which includes its locked forms, absorbed and adsorbed) and the products of partial incineration of thin coalbeds, riders and seams from thee suite. The second stage consists in deep degassing and unloading of coal beds which sharply reduces the hazards of methane explosion and rock bumps, thus increasing the productivity of mechanized coal mining. During the second stage coal is mined in long poles with the account of degassing and unloading of coal beds, plus the data on gas dynamic structure of coal rock massif

***Key words*:** coal bed suite, gasification, comprehensive technology, degassing, geodynamic zoning, methane.

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Introduction. Currently there is a wide global discussion going on the future of coal industry. Many experts claim that a single Joule of energy produced during coal combustion generates 1.5 times more CO_2 and other greenhouse gases than that from natural gas and petrol products in addition to large amount of dust and suggest to lower consumption of coal in favor of ‘environmentally friendly’ renewable energy sources (wind, solar radiation, biofuels, etc.), as well as hydrocarbons, especially natural gas. That idea meets certain welcome not only in the Western countries that show the strongest environmental concerns but in China as well where the scope of mining and consuming coal is huge (1/2 of its global production), resulting in the formation of heavy smogs and deterioration of the environmental situation. Yet minor but widely discussed cutbacks in coal mining in China and the US against the weak growth of global economy and general drop in prices for raw materials are pulling coal prices down too, so cost effectiveness of mining coal is reduced.

High methane content of Russian coals (especially the Kuznetsk basin ones) make them a potentially promising raw material for gas extraction. Theoretically Russia could outrun the US in that respect, the latter featuring a stable level of extracting coal methane at the level of 8-10 % of the country total gas mining, however the domination of absorbed and even adsorbed methane complicates degassing and turns methane into a hazard instead of a valuable raw material while also making mining more expensive [11, 13, 14].

One of the ways out from such a situation is underground degassing suggested way back in the 19 century by W. Simmens, D.Mendeleev and W.Ramsey, that used to be a wide practice at many coal deposits of the former USSR.

The first in situ degassing of the protective layer preventing geo- and gas-dynamic manifestations in other coal beds was studied in [1-3] and proposals to develop the technique further were put forward in [7-10] and other studies.

Study Methods. The current study considers the in situ gasification of the protective underlying coal bed in the suite not only as a technique to off-load the suite thus decreasing the risk of rock bump and rock ejection while mining the beds lying above, but as a way to increase sharply the level of degassing the upper coal beds and extract methane and retrieve most of the energy of coal-methane deposits. Also it would help separate full processing of the coal suite into two stages: extracting its gaseous products, one, and then mining its off-loaded degassed coal, two.

The comprehensive technology combining in situ gasification of coal in the lower beds in the suite of bump hazardous gas rich beds with the ensuing extraction of coal methane solves a number of tasks in parallel.

• Off-load productive coal beds and reduce their bump hazard due to burn-out of the protective bed.

• Increase the efficiency of degassing the operational coal beds due to off-loading them.

• Increase the intensity of methane desorption in operational coal beds due to conductive and partially convective heat transfer through intra-bed rock.

• Decrease the strength and weaken the rock bump hazard for coal in operational coal beds due to transfer of combustion products through the bed (CO and specially CO_2).

• Degas coal containing layers and alternations in intra-bed space via their partial burnout in the course of gasification or accelerated degassing under strong heating.

• Increase the calorific power of gasification products via their dilution with methane produced in the course of degassing upper beds.

• Decrease methane emissions, that gas having a stronger greenhouse effect than carbon dioxide.

One of the principal objections against in situ gasification (similar, by the way, to objections against mining shale gas and shale oil) consists in the possibility of poisoning ground waters, water basins and water intakes. That risk is minimized with the discussed technology, as gasification takes place at large depths and the principal mss of water is evacuated from combustion zone by the mine systems of degassing and water evacuation which makes possible it cleaning.

As demonstrated by the experience in underground gasification [7-9], that technology is most effective for those coalbeds that meet the following requirements:

• the coalbed is lying at the depth of 30 to 800 m;

• the coalbed is of considerable thickness, at least 5 m desirably;

• coal ash content should not exceed 45 %;

• the sector of the bed subjected to gasification has no apparent break-up faults.

Study results and their discussion. In the considered case the second requirement is obviously not satisfied because it is more cost-effective to work out powerful beds using the mine technology, while protective gasified beds should be picked among the relatively thin beds (from 0.5-0.7 to 1.5-2 m). In some cases it may appear problematic to meet the first requirement too, since the bottom coalbed of the suite may lie at large depths up to 1 km and more. It is especially difficult to meet the last requirement, since the low lying bump hazardous beds are under high vertical and horizontal stress and feature high density compact stricture.

That is why it becomes especially important to select rationally the sector from which the gasification process will start. That sector should lie in a tectonically off-loaded zone feature high seaminess, also preferable are low water cut and higher methane content. In other words gasification should start from the sectors that are most favorable for degassing in case the suite would be developed following a different technology.

Searching for tectonically off-loaded zones is done according to geodynamic zoning technique. The technology of geodynamic zoning includes, first of all the reconstruction of geological-structural model of the massif within the scope of mining allocation and its surrounding zone, built on the basis of morphological and structural analysis of topographic maps and the river system, plus formal and informal techniques for deciphering outer space pictures which highlight the position of faults as rectified elements of terrain and river system, bands (arcs) of contrasting colors, etc. The next stage consists in correlating the drawings of fault system retrieved by different techniques to yield the block structure splitting our zone into different blocks, hypsometrically contrasting, relate that to the density of river network, orientation of seaminess, etc.

After plotting the block structure the tensions across our studied zone are retrieved using various digital simulation techniques to model the deflected strain mode (DSM) of the system. The methods that have found the widest recognition are the Finite Elements Method (FEM), the Finite Differences Method (FDM), the Boundary Elements Method or the Method of the Boundary Integral Equations (BEM or BIE) and the Different Elements Method (DEM).

Figure 1 demonstrates applying the BIE method (BLOCKS2D package, [6]) to assess the tensed state. To model the distribution of tensions in the block structure we considered their flat cross-section parallel to the ground surface with the following ratio of chief tensions: $(\sigma_x/\rho gh) : (\sigma_z/\rho gh) = 2.0 : 1.2$ (σ_x – latitude-wise directions σ_z – meridian-wise directions). Fig. 1 gives the results of computing tensions σ_x and σ_z within the scope of the identified system of blocks formed due to the presence of active fault zones (green color highlights the block limiting the area of the Talda zone).

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The zones most off-loaded where the process of in situ gasification are situated near the crossings of faults or zones of their concentration which agrees with the accumulated statistics on methane mobility in coal fields.

Variability in optional plotting of block structure and the unreliable character of assessing the characteristics of fault zones used in our calculations prevent using the data of geodynamic zoning without some external control. Such a control technique consists in testing coal samples retrieved from test boreholes on their gas content. Due to significant differences in coal gas collection properties, experimental estimates of methane content vary widely even within limited areas. By way of example consider the estimates for the "Shurapsky" site of the Kedrov-Krokhalev coal field. According to the data of test drilling the methane content of the Kemerovsky coal bed varies from 2.2 to 22.7 m^3/t, that of the Volkovsky coal bed – from 9.4 to 35.4 m^3/t, that of Podvolkovsky – from 15.3 to 27.5 m^3/t. Comparing the results of mathematical simulation with the statistical analysis of the drilling data makes it possible to locate most reliably the zones of depleted tension and higher methane content that fit the task of starting in situ gasification.

The second step coming after the selection of site is well drilling. Wells of three different types (uses) are needed for this particular technology: the blasting, the gas evacuating, both drilled to the gasified coal bed, and also those drilled into the degassed working coal bed (Fig.2). Further into the process the role of wells changes, so each well works as the blasting, the degassing and the gas evacuating one. As indicated by the experience of in situ gasification, the most efficient way is to have well of relatively large diameter to be able to use pipes of high throughput capacity for blasting and evacuating combustion gases. For target drilling the drilling rigs are fitted with control instruments and gyroscope incline meters, all done in advance.

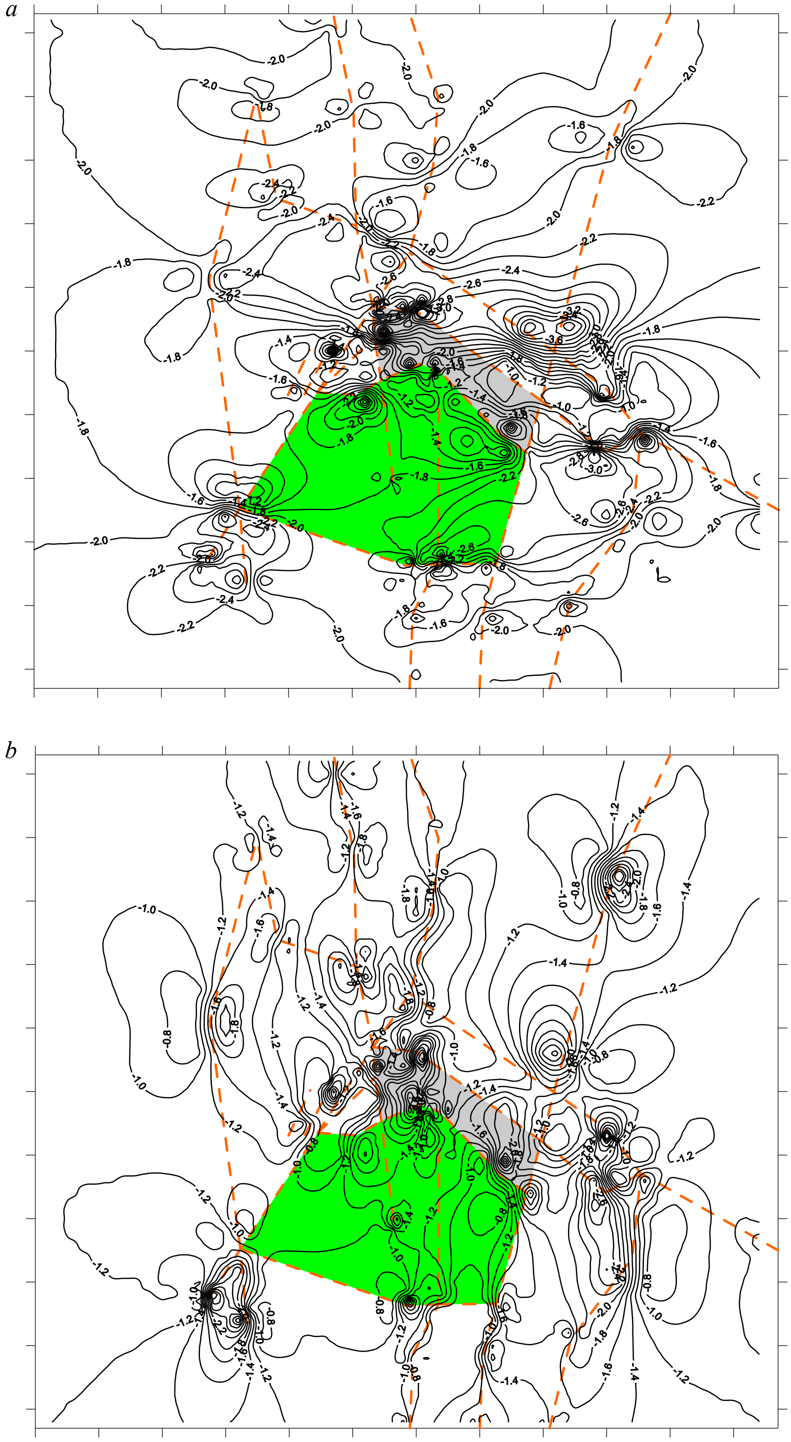

Fig.1. Prognostic map of tensed stateσ_x (*a*) and σ_z (*b*)
the block massif of rock types of the Talda zone, Kuzbass

The third stage is producing gas permeable canals between the blasting and gas evacuating wells that will work as an underground gas generator. It is done in several ways:

– fire filtration well linking;

– Hydraulic fracturing of coal bed by liquid or gas with the ensuing firing of the fissure produced in the coal bed (Fig.2);

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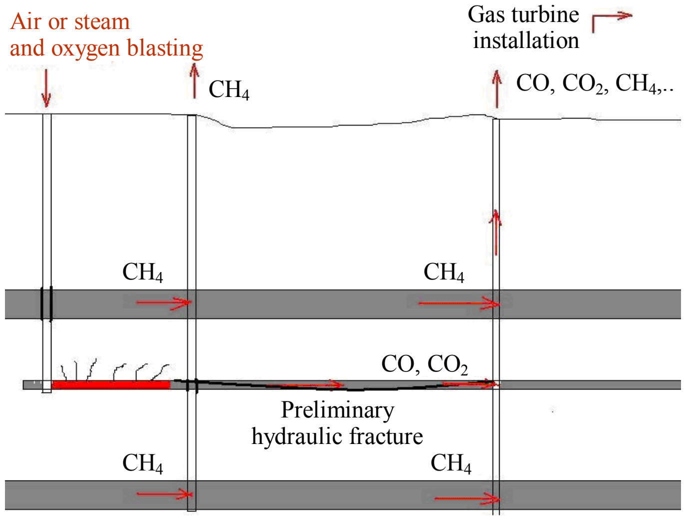

Fig.2. Degassing via in situ gasification of one of the lower weak coal beds in the suite

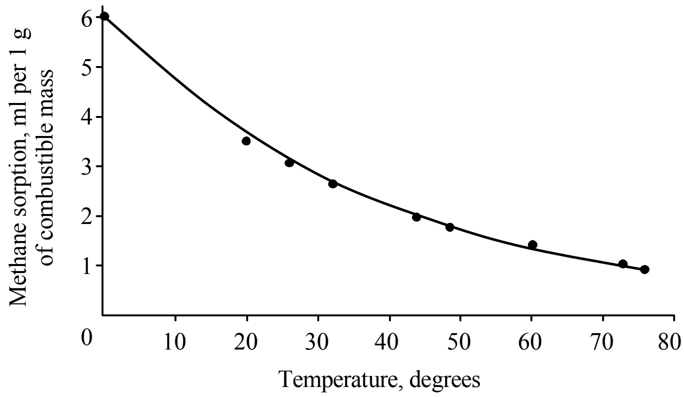

Fig.3. The dependence of coal sorption capacity on temperature

– drilling with the ensuing firing of slanted and horizontal fire canals.

The choice of this or that technique depends, first of all, on the specific mining and geological conditions and is updated in the course of designing the project. With high water inflow to the gasification zone the temperature drops significantly within the range of influence of the zone of fuel combustion. Practical experience demonstrates that the underground gas generator is effective up to water inflows of 0.6 m^3 of water per 1 of gasified coal. Therefore, when water inflow to gasified coal bed is too high and (or) when hydraulic fracturing is used the gasified area should be dried. Water removal from the kindling zone is provided by continuous blasting at high pressure that exceeds the bed pressure of ground water.

An important element of the designed technology is heating the intra-bed rock mass and the operational coal beds in order to increase degassing efficiency. For a preliminary assessment of the effect of heating on desorption of methane one may use the experimental graph plotted by I.L. Ettinger [12] for the coals of Karaganda basin (Fig.3) and the empirical formula by G.D.Lidin:

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

where x_p is coal sorption capacity for methane, m^3/t; V is the output of volatile components by the flammable mass, %; P is the pressure, atm; W is humidity, %; a and b are coefficients depending on the degree of metamorphism. It is important to note that the dependence of methane sorption capacity of coal on temperature, t is quite general and close for various mining and geological conditions, while the effect of temperature is more significant than that of pressure (stratification depth).

To provide for the maximum transfer of heat one needs a high a combustion temperature as possible, on the one hand. On the other hand, high rates of combustion and extraction of gasification products lead to depleting the amount of heat transmitted to the enclosing strata. On the third hand with the intra-bed layer being thin there is a risk to ignite the powerful working coal bed. With all that in mind three options are suggested for the technology of underground gasification.

1. For low thickness of intra-bed coal seam (up to 30-35 m, where m is the thickness of gasified seam) it is recommended to use air blasting that produces less intense combustion. Air blasting may also be recommended for small stratification depths of gasified seam. In such cases heat losses will be relatively small and gasification canals will be formed effectively in the seam.

2. For large thickness of intra-bed layer the risk of igniting the working coal bed becomes insignificant and the requirement more important for successful operation becomes it efficient heating. In that case steam and oxygen blasting becomes optimal, as it provides higher combustion temperatures (up to 800-1000 °C). Meanwhile combustion intensity should be kept at a minimal level to keep the process stable.

3. At large intra-bed thickness direct heating of the working seam by direct heat transfer becomes slow and inefficient. In that case the gas produced may be used to heat additionally the gas collector thus formed via degassing wells. To hest thoroughly a powerful seam and intensify the process of de-

gassing one or several wells are periodically alternated so that combustion products are put through the seam first instead of sending them direct to the gas turbine unit (Fig.4). Combustion products, CO and CO_2 in particular help to deplete coal strength and accelerate methane desorption [4].

In the course of gasification the intensity of combustion may sometimes weaken, first of all in the zones off geological faults including small amplitude break-up and plicative faults, pinches, thinnings and changes of seam curvature.

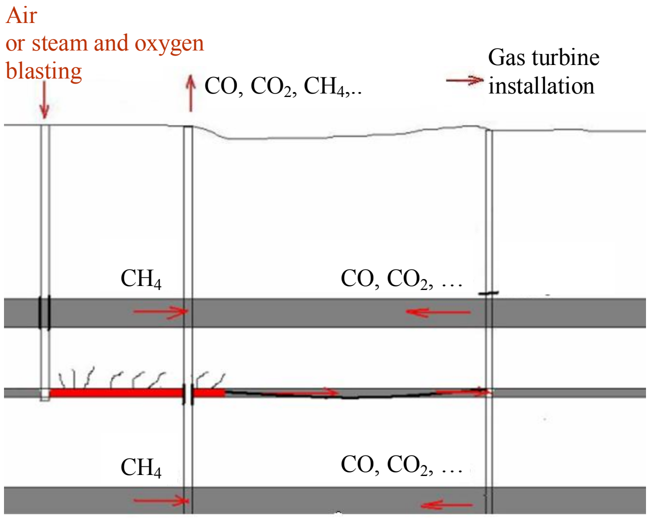

Fig. 4. Periodic intensification of degassing by sending combustion products through the seam

Preliminary forecasting of the position of such areas is done using data from geodynamic zoning and mathematical modeling of DSM of the massif with the account of data from test drilling. For example (cf. Figs.1, 2) the zone of excessive latitudinal strain ($\sigma_x/\rho gh > 2{,}0$) is observed in the NW part of the block limiting the area of the Talda site. The areas of excessive meridional strains ($\sigma_z/\rho gh > 1.2$) are located at the corners of the block limiting the area of the Talda site, while the central part of the block has an observable off-load zone. Generally, the results of calculations indicate the block most strained is the one over the northern part of the Talda site (highlighted in grey in Fig.1), and the seismic activity of that area points to the same [5].

Intensification of the gasification process in these areas is also possible by means of an inverse process, i.e. pumping part of the extracted methane back to combustion zone. Beside, to sustain stable and controlled gasification process the authors have designed and tested in both the lab and field environments (using the steam generation unit at the Angren Power Plant) various technological methods based on introducing liquid reagents into the zone of probable extinction squeezing them through the coal bearing rock.

To control the contours and scope of gasification three different methods were used:

• by the volume of gaseous products;

• by the results of observing land surface deformation;

• tracing the position of combustion front with electromagnetic mapping technique designed by the authors.

The composition of gas obtained and its calorific capacity depend quite significantly on the blasting used and local coal properties. In case air is used to be blasted into the gasified coal bed low calorific gas is released, its calorific capacity about 4-5 MJ/m^3. Such a combustible gas may be successfully used in gas turbine units, their generated electric energy to be spent on drilling degassing wells and running compressors and pumps. In case steam and oxygen blasting is used for coal gasification a gas of medium calorific capacity is produced, its value up to 10-13 MJ/m^3. Combining the process of gasification with degassing of operational coal beds makes it possible to retrieve medium calorific capacity gas with air blasting and high calorific capacity gas (from 20 MJ/m^3 and higher) with steam and oxygen blasting.

Power gas obtained in the course of underground gasification to produce heat and electric energy contains valuable chemical components as well: resin, phenol, hyposulfite, sulphur, etc. Therefore it is economically feasible to use chemical raw products yielded by the process of gasification and extracted from the condensate formed in the course of gas cooling and treatment. In particular these include ammonia, phenols as well as resins that may be stricken as marketable products. Content of chemical components during underground coal gasification, per 1 m^3 of gas extracted, g/m^3: gas condensate – 140-150; ammonia – 2.0-2.5; benzene hydrocarbons – 1.0-2.0; resin – 0.3-0.6; pyridine bases – 0.5-0.7; hydrogen sulfide – 0.3; naphthalene – 0.1-0.9; acetylene – 0.003-0.1; hydrocyanic acid – 0.007.

Resin handling may follow two directions in dependence of the economic conditions: composite sediments (mechanical admixtures and heavy resins – "fuses") are burnt in boilers together with coal; composite sediments are used to produce asphalt for road building.

The experience in treating the obtained gas indicates that the degree of cleaning condensate from ammonia reaches about 98 %, the output product being 25 % ammonia water. After purifying condensate from ammonia, phenols are extracted from waste water as sodium phenolite. Phenol-free condensate is dumped to biochemical treatment, the degree of phenol extraction being about 90 % [7, 9].

Conclusion. The newly designed technology will make it possible to involve industrial deposits of coal from bump-prone gas containing suites and open the way to comprehensive use of power and chemical resources of coal and methane deposits. Due to the offered technology a two-stage process of developing coal and methane deposits becomes possible.

During the first phase the methane-coal deposit works as a gas deposit only, without driving, tunneling or mining, the gas having two sources – extracted methane (which includes its locked forms, absorbed and adsorbed) and the products of partial incineration of thin coalbeds, riders and seams from the suite. That stage is also preparatory for entering into the second stage, which consists in deep degassing and unloading of coal beds which sharply reduces the hazards of methane explosion and rock bumps, thus increasing the productivity and safety of mechanized coal mining.

During the second stage coal is mined in long poles with the account of degassing and unloading of coal beds, plus the data on gas dynamic structure of coal rock massif retrieved during the first stage of operation.

Suites of great thickness may be split into several sections according to their depth and alternate first and second stage operations.

Thus the proposed technique makes it possible to obtain gaseous fuel without proper mining, extracting it from suites of rock seams. The total productivity of the technique may reach 15-20 % of energy contained in coal suite. Note too that the first stage does not result in disintegration of basic seams; quite the opposite, it gets them prepared for mining (due to off-load and degassing), depleting the rock bump hazard and methane hazard so that coal beds of the suite may be mined using traditional techniques during the second stage.

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