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STOWING AS THE METHOD OF MINING PRESSURE CONTROL DURING UNDERGROUND COAL GASIFICATION

A world power market, in the long-term prospect, specifies by limited supplies of oil and gas, more difficult conditions of coal mining that results in the continuous price grows on energy resources. Coal is the unique power medium that in the near future can satisfy world necessities in energy. It is widely used not only in energy but also in the chemical industry.

The efficiency of Ukrainian industrial complex is related to the development of the coal industry. Coal is the primary source of raw material for the power complex of country. Its reserves are 97,4%, gas and oil reserves are 2,6%. Taking into account the losses at mining which are to 40%, coal resources will last for 300–350 years.

It is difficult to extract coal by underground methods, because of mining on greater depths and worsening geological conditions. The possibility to increase coal mining is rather limited. It is necessary to develop progressive, environmentally clean technologies of mining. Underground gasification of coal is an effective solution of this problem, with thermo chemical processing of coal in place of its bedding in combustible gas.

In comparison with underground and opencast mining, the underground mining holes coal gasification (UMCG) liquidated the complicated and hard work of miners, doesn't destroy the agricultural lands, and eliminate the necessity of gobing on the surface.

In comparison with surface gasification, the underground gasification requires less capital charges, that enables to get cheaper power medium (gas).

In order to produce thermal and electric energy from UMCG gases additional preparation is not needed. The products of gases combustion do not contain the carbon oxide, hard particles, and sulphur anhydrite. Content of nitrogen oxides is insignificant. High speed of gas combustion (1,6 m^3/s) allows to use it in industry and for social purposes. Gasifica-

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tion gases and products can be use in the chemical industry because of the deficit of natural gas, oil, sulphur, ammonia and methanol. Practically above 78% of black and 34% of brown coals in Ukraine can be used for underground gasification of coal.

The negative phenomena of UMCG are: low heating of gas combustion, presence of losses of gasification products, ecological instability of the process of underground gasification and large volume of drilling and preparatory operations that increase at in the primary price of gas to 30–35%.

Traditional technologies of underground coal gasification practically do not allow managing the process and having some negative phenomena in the construction of underground part of gas-generator. There are losses from 10 to 20% of blowing, and 14–36% of productive gas. Also, gasification is not providing the necessary thermal and output-input ratio of chemical processes and output of gases with the promoted heating value.

One of the solutions of this problem is the increase of impermeability by injecting of stowing material in the deformed rocks of roof and fulfilling of goaf. Absence of sufficient scientific ideas on technological parameters and schemes of goaf fulfilling, prevent to create more effective technologies of underground coal gasification. It is actual to develop the UMCG technological schemes with the fulfilling of the produced space underground gas-generator.

The solution of this problem foresees the research of tensely and deformed conditions of rockmass during underground coal gasification.

Critical analysis of practical and experimental underground gas-generators exposed the reasons of less reliability of constructions and process of underground gasification. This process is conducted with the creation of emptiness which is stipulated in rockmass. These zones influenced by complex tensions, caused by mining pressure and thermal loadings.

The original method developed at National Mining University (method NMU) for the analysis of rockmass at the extraction and coal gasification was chosen [2]. It allows developing the mathematical model of rockmass taking into account the features and process of coal gasification.

There were conducted analytical researches of the stressed-deformed conditions of the rockmass, with substantiation of dynamic and parameters of cavities forming in rockmass that contains a gas-generator and technological parameters of the process of coal gasification.

A mathematical model imitates the change in rockmass near the underground gas-generator. It reflects the features of this change (stratification, creation of vertical displacements and cavities, and motion of rock layers) and allows researching the presence of stratification cavities and change of their sizes depending on natural factors and technological parameters.

The input data for the calculation are taken from the geological constructions of mining holes, and technological parameters of gasification process. In accordance with the criteria of coal possibility to underground gasification, the areas of the coal deposit in Western Donbass OC Pavlogradvugillia» with the depth of exploration 170–340 m were selected.

The data about geological conditions of gasification area and technological parameters of the UMCG process are put to the computer. The software developed at the NMU was used. Geometrical, physical parameters, lowering and horizontal movement of rock layers are given in tables, graphs and epures.

Distribution of loadings on the layers above a gas-generator at extracting a thin coal layer is presented on Figure 1.

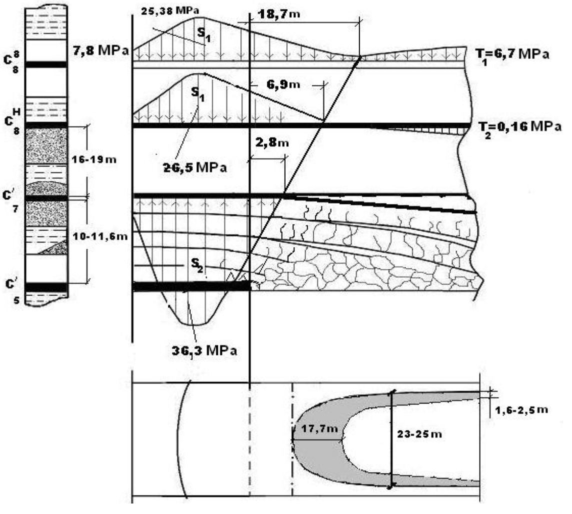

Fig. 1. Distribution of the normal loadings in the rocks above the gas-generator

Figure 1 shown that supporting zone at the coal seam which is gasificated with speed $1^{m}/_{day}$, is located in the distance 2,8 m from fire face above the underground gas-generator. Cavity of stratification is formed on the distance between 10-11,6 m above the goaf. Changes of parameters of cavity formation above the gas-generator are shown on Figure 2.

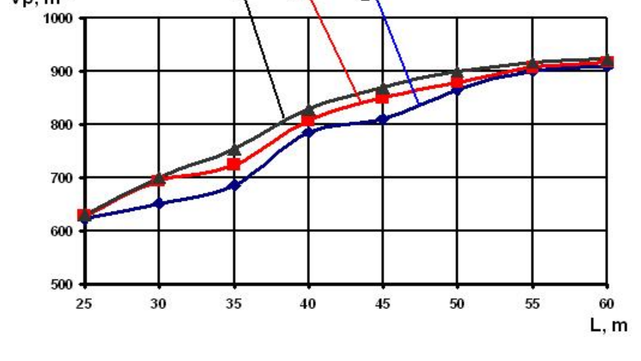

Fig. 2. Dependences of cavities parameters from speed of fire face:
1 — at speed of advancement of fire face $V = 0{,}5\ ^{m}/_{day}$; 2 — $V = 1{,}0\ ^{m}/_{day}$; 3 — $V = 1{,}5\ ^{m}/_{day}$

The cavity of stratification is closed as far as fire face advancement and increase of goaf. Upon termination of coal gasification at length 100 m, its height does not exceed 76 mm, and volume 81 m^3 depends on the change of technological parameters (Tab. 1).

TABLE 1

Change of cavity parameters at UMCG

Length of gas-generator channel, m	Speed of advancement of fire face, $^{m}/_{day}$								
	0,5			1,0			1,5		
	h_{max}, mm	$V_{p\ max}$, m^3	$V_{p\ min}$, m^3	h_{max}, mm	$V_{p\ max}$, m^3	$V_{p\ min}$, m^3	h_{max}, mm	$V_{p\ max}$, m^3	$V_{p\ min}$, m^3
60	314	910	210	321	917	221	326	924	227
30	235	652	100	240	694	81	244	702	86
25	194	623	89	181	628	72	180	631	75

Changes of cavities volume, taking into account the change of technological parameters (lengths of fire channel of underground gas-generator and speed of coal gasification), take place the in linear dependence. The volume of cavity changes in 610–924 m^3, the height of stratification varies in limits 181–326 mm (Tab. 1).

With the increase of speed of fire face advancement, the height of stratification cavity above the middle of goaf is multiplied. Its width diminishes due to displacement of scopes of supporting zone (Tab. 2) toward goaf.

TABLE 2

Changes of parameters of supporting zone depending on technological factors

Speed of fire face, m/day	Length of reactionary channel of underground gas-generator, m											
	25				30				60			
	geometrical parameters of supporting zone, m.		maximal supporting loading, MPa.		geometrical parameters of supporting zone, m.		maximal supporting loading, MPa		geometrical parameters of supporting zone, m.		maximal supporting loading, MPa.	
	a	d_0	$S_{1.2}$	S_2	a	d_0	$S_{1.2}$	S_2	a	d_0	$S_{1.2}$	S_2
0,5	$\frac{24}{7{,}6}$	$\frac{14{,}7}{6}$	23,8	19,1	$\frac{20}{6{,}1}$	$\frac{17{,}5}{5{,}9}$	21,1	24,5	$\frac{20{,}3}{7}$	$\frac{15{,}1}{6}$	27,5	20
1	$\frac{20{,}8}{6}$	$\frac{11{,}5}{5{,}3}$	20,8	20,3	$\frac{18{,}7}{5{,}1}$	$\frac{16{,}4}{5{,}6}$	21,8	25	$\frac{17{,}6}{5{,}8}$	$\frac{15{,}8}{5{,}7}$	23,1	21,7
1,5	$\frac{17{,}4}{5}$	$\frac{12{,}5}{4}$	19,6	25,2	$\frac{18{,}5}{4{,}7}$	$\frac{17{,}3}{5{,}4}$	21,7	26,4	$\frac{16{,}3}{6{,}1}$	$\frac{14{,}8}{5{,}4}$	21,2	24

Behavior of rocks of basic roof of underground gas-generator is not influenced by thermodynamic loadings due to less temperatures and large heat capacity of rock layers (clay slate) of basic roof.

Taking into account the critical loadings from rockmass, which are spread to the geometrical point of bend and condition of rock resistance of basic roof on splitting off 11,9 MPa, on compression 34 MPa, and on tearing by stratification 0,015 MPa (Tab. 3) deformation of rocks of basic roof will not be observed.

TABLE 3

Critical deformations, lowering and movement of rocks of basic roof

Length of reactionary channel, m	Type of deformations in the rocks of basic roof	Examined section of fire face, m						
		7,2	12,0	16,5	18,3	24,6	31,4	35,2
30	Deformations, mm/m	5,5	5,6	5,3	–5,1	0	–3,9	0
	Lowering, mm	74,0	222	511	555	619	838	303
	Movement, mm	51,3	174,1	180,5	211,4	160,2	52,2	0

In order to form deformation, the creation of plastic hinge at total tensions not less than 88 MPa is required. Compressive stresses on the in the considered section do not exceed 51,7 MPa (Tab. 4).

TABLE 4

Tensions in the rock layer of basic roof in the section L = 32,5 m

Location of section, m	Transversal force Q, MN	Moment M, MN m	Bending stresses, MPa			
			$\sigma_{сж}$	σ_p	$\sigma_{от}$	τ_{max}
12,0	25,8	1,0	0,075	0,05	0	4,81
35,2	0	956	51,7	10,3	0,02	0

Under these conditions, there is the smooth lowering of basic roof with creation of vertical cracks with intensity 6–8 cracks for 1 m of face movement. Stratification of basic roof is divided into three layers of thickness 1,8 m; 2,2 m and 2 m.

The direct roof is divided into two rocks parts by thickness of 2 m. Such a roof condition depends on the parameters of loading from the basic roof, high temperatures, ash content, and rock structure of roof and footwall.

The direct roof is mainly presented by clay slates which belong to the thermo resilient plastic rocks. Taking into account the unevenness of temperatures distribution in the reactionary channel of underground gas-generator, at the maximum of temperatures 1200°C in the transfer point of oxidizing zone in restoration one, the gradient of rocks heating of roof is 30,1–52,4°C/0,1 m (Fig. 3).

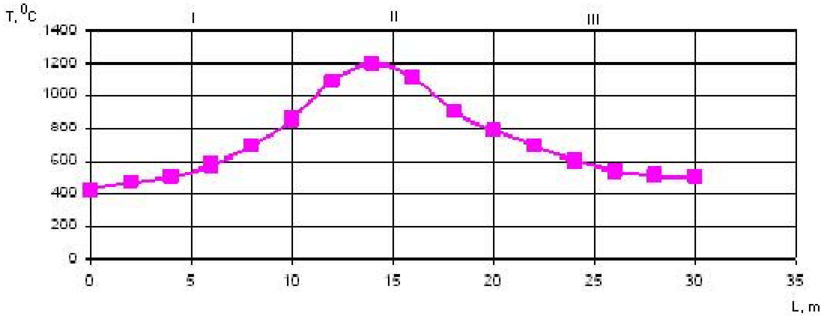

Fig. 3. Distribution of temperatures on length of reactionary channel (I — oxidizing zone; II — transition border; III — restoration zone)

At heationg roof rocks to 1000°C on the depth of 0,45 m from fire face, there is stratification of rockmass. In the temperatures range 1100–1150°C on the depth 0,2–0,35 m the intensity of stratification increases. At the temperature 1200°C on the depth 0,1–0,15 m rocks change into the plastic state (melting) [3, 4]. Main components of mineral composition (SiO_2 — 61,7%, Al_2O_3/SiO_2 — 0,18% and C — 1,04%) will not result in the substantial rise of lower pack of rocks of direct roof, that means gas-generator is not affected to the deformations.

From calculation data (Tab. 5) the characteristics describing horizontal movement and lowering of rocks of direct roof in a supporting zone and goaf are made.

TABLE 5

Lowering and stresses at the bend of lower pack of rocks of direct roof at different speeds of fire face advancement

Tension, MPa			Lowering, mm		Movement, mm		Advancement of face, $^m/_{day}$	Physical parameters, MPa	
$G_{сж}$	G_p	G_{max}	Above the face	29,6 m, from face	Above the face	T_{max}	V	S_1	S_2
3,06	8,1	3,3	$\frac{24}{218}$	929	$\frac{57}{191}$	253	0,5	10,7	12,1
31,3	8,4	3,7	$\frac{25,2}{220}$	949,7	$\frac{57,6}{193}$	253,6	1,0	11,9	14,6
33,6	8,91	3,96	$\frac{26,5}{221,2}$	964,3	$\frac{58}{194,8}$	254,4	1,5	12,8	16,3

It should be noted, that at the increase of speed of fire face advancement, a supporting zone diminishes from 11 to 6,8 m. Rocks movement changed insignificantly, that leads to deformations with speed 4,8–5,7 mm/min (Fig. 4).

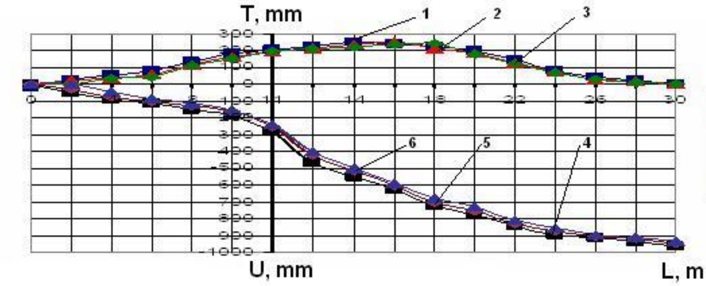

Fig. 4. Horizontal movement (T) and lowering (U) of rocks of direct roof at different speeds of face advancement (1, 6 — 1,5 $^{m}/_{day.}$, 2, 5 — 1 $^{m}/_{day.}$, 3, 4 — 0,5 $^{m}/_{day}$)

At such deformations in the rockmass there is the active creation of horizontal and vertical rock displacements. The physical parameters of supporting zone increase in the roof by 10,7–12,8 MPa, in the footwall by 12,1–16,3 MPa. This testifies the active deformation processes in the rocks of supporting zone 9,3 MPa, on the compression 19,0 MPa, on tearing off, on stratification 0,12 MPa, that results in the well-organized deformation of layers with cracks formation.

Rocks of direct footwall raise by 78–446 mm, taking into account thickness of ash slams (9,6–10,8 mm), that is the half coal seam thickness (Fig. 5).

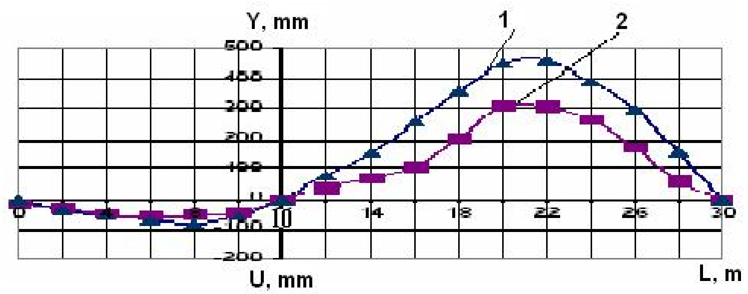

Fig. 5. Dependences of movement of footwall rocks:
1 — raise of footwall rocks taking into account temperatures;
2 — raise of footwall rocks without taking into account influence of thermodynamic tensions

According to Table 5 and Figure 5 it is possible to note that the resistance of rocks of direct roof on splitting off is 9,3 MPa, on the compression is 19,0 MPa, on tearing on stratification is 0,12 MPa. In such conditions, there are insignificant destructions and they result in the formation of vertical cracks (width of cracks — 2–5 sm, deformation 6,2–7,1 $^{mm}/_{min}$). As a result of these processes, there is the smooth lowering of direct roof with the breaks of footwall.

At the change of speed of fire face advancement and at the increase of length of channel during gasification, there is falling of roof rocks. It is related to the change of parameters of supporting zone and increase of length of semiflight of underground gas-generator.

It should be noted that rocks falling is not observed on the length of reactionary channel in an interval 14,8–18,3 m (transition of oxidizing zone in restoration one). In this area under the action of high temperatures, clay slate changes to the plastic state on a depth 15–25 cm. At the different distance from fire face in goaf, rock of roof cools off and fluently goes down up to the footwall.

According to the mathematical model, with the increase of gasification speed, the goaf diminished on length of gas-generator channel and in a volume.

Conclusions

1) The physical model of the mathematical mechanism and the algorithm of calculation at UMCG allow:
   - to take into account stratifications, creation of vertical cracks and cavities, displacements of rock layers and other processes of mining pressure and thermodynamic loadings;
   - to determine stresses and deformations in rockmass according to geological and technical factors, including the features of coal gasification;
   - to substantiate a dynamic and parameters of stratification cavities and to determine the rational parameters of technology of injection fulfilling goaf after underground gas-generator.
2) The analysis of the executed analytical research allows making conclusions for the mines of Western Donbass coal basin, which are potentially suitable to gasification:
   - substantial influence on the formation of stratification cavities in rockmass has physical and mechanical properties of rocks, structure of massif and technological parameters of gasification;
   - speed of cavities opening of stratification at different depths (210–340 m) of coal gasification changes with the increase of depth by 6–9%.
   - at varying length of fire channel from 25 m to 60 m and speed of advancement in 0,5–1,5 $^{m}/_{day}$, the maximal volume of cavity is changed by 610-924 m^3, with a maximal height of 181–325 mm.

3) Parameters of cavity and place of its formation depend on physical and mechanical properties of single hard rock layer and structure of rockmass. Practical researches show that stratification of rockmass takes place above goaf in the distance between 9,6–14 m higher than underground gas-generator.

4) Closing of cavity takes place in the distance 0,75–2,8 m from the regional zones of gasification, with diminishment of height of cavity to 76 mm and volume to 81 m^3.

5) Cavity stratifications do not appear higher than single hard layer above it distribution of normal loadings is near to the gravitation forces.

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