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THE IMPROVED EMPIRICAL AND NATURALISTIC METHODS FOR FORECASTING METHANE CONTENT IN THE COAL SEAMS

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УСОВЕРШЕНСТВОВАННЫЕ ЭМПИРИО-НАТУРАЛИСТИЧЕСКИЕ МЕТОДЫ ПРОГНОЗА МЕТАНОНОСНОСТИ УГОЛЬНЫХ ПЛАСТОВ

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ВДОСКОНАЛЕНІ ЕМПІРІО-НАТУРАЛІСТИЧНІ МЕТОДИ ПРОГНОЗУ МЕТАНОНОСНОСТІ ВУГІЛЬНИХ ПЛАСТІВ

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Abstract. The problem of determining methane content in the coal seams was being solved actively in the 1960s-1980s since there was a need to improve design reliability of gas safety systems in the mines. Today, mine methane is considered as a nonconventional material in the energy industry and in terms of improving safety, environmental friendliness and technical and economic efficiency of the operating mines. Hence, solving the problems of reliable determination of methane content in coal deposits has become topical again. The research is related to the field of the mine gas safety and assessment of methane reserves in the methane-coal deposits. A scope of literature and stock data were summarized, and empirical methods for determining methane content in coalbeds were improved (statistical geological, mining statistical and semi empirical methods). Impact of tectonic structures of coal deposits on the methane relative content was determined. Pattern of depth effect on methane content in the coal seams was established. The mining statistical method for forecasting gas emissions was improved by taking into considerartion effect of depth, rock inclination, seam thickness and methods for controlling rock pressure on the gas emissions from the coal seam. The quantitative estimation of methane share emitted from the mine rocks in the total gas balance of the mining site was done. The semi-empirical method for predicting methane content in coal seams was improved by taking into account the Hilt-Skok's law and the established patterns of the effect of unloading, depth and strength of rocks on thermobaric conditions, which predefine gas content in the coal seams. The research results were implemented in the projects of Dneprogiproshakht Institute. The evidence-based part of the improved methods were presentred in different scientific reports of the N.Poljakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine and Dniprogiproshakht Institute.

Keywords: empiric-statistical methods, proognosis, methane content, coal seam, gas emission from the coal seams.

Introduction. The problem concerning determination of methane content in coal seams was being solved actively in the 1960s-1980s since there was a need to improve design reliability of the systems of gas safety in mines [1, 2, 3].

Currently, mine methane is considered to be nonconventional material in the energy industry [4, 5, 6]; and to improve safety, environmental friendliness, and technical and economic efficiency of operating mines [7]. Hence, solving the problems concerning the determination of methane content of coal deposits has become topical again [8, 9]. Three empiric methods are used to determine methane content of coal deposits [1, 2, 3]: geological and statistical method, mining and statistical method, and semi-empirical, all of them differ in application area, resolving power, and completeness of factors taken into consideration.

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Methods. The methods of generalization, analysis and synthesis of the materials which were published and stock materials were used to achieve the goal taking into account the specifics of the tasks to be solved.

Geological and statistical method has been improved by means of comparative and statistical data analyses taking into consideration factors differing qualitatively: tectonic conditions (i.e. synclines, anticlines, and monoclines); gas belts differing in depth effect on methane content (i.e. coal, semianthracite, anthracite, and superanthracite); gas zones (i.e. weathering zones, gas-undersaturation zones, gas-saturation zones, and zones degassed partially); occurrence of coal seams within tectonic folds (i.e. wings, joints, bottom part or axial part, and transition zones of gas belts).

Improvement process of mining and statistical method involved generalization of actual methane release into workings of production units in mines of Central Donbass within depth interval down to 900 m; moreover, average weighted gas content of levels, methane release from complementary rocks, and rocks used to improve G.D. Lydin technique as for gas recovery of coal seams and rocks have been identified.

Semi-empirical forecast method as for methane content has been developed while combining Langmuir and Hilt-Skok's solutions, completed with regularities of depth effect as well as rock properties effect on thermobaric parameters of the Earth's crust, determined by the author on the basis of experimental data generalization.

Results and their discussions. The empirical methods have been improved by way of generalization of the geological data in order to specify methane reserves in the coal deposits of Donbass.

Geological and statistical method

The following has been determined in elaboration of geological and statistical method:

- regularity of effect of tectonic structure of deposits on the methane content value: if other conditions are equal, methane content of coal seams occurring within synclinal folds is the largest; the value is the least for seams occurring within anticlinal folds; and the value is average one in the context of monoclonal occurrence.
- math expression of regularity of depth effect on methane content of coal

$$X = \frac{H - H_0}{a + b \cdot (H - H_0)}, \text{m}^3/\text{ton} \qquad (1)$$

differs in the following: first, while deepening (irrespective of coal grade) function (1) tends to common limit $X_{max} = X_T$ being equal to maximum methane content value of lean coal; second, ordinate of function (1) vertex is H_x depth, separating gas undersaturated coal zone (upper), and gas saturated one (lower); and third, values of empirical constant α have been determined: 5.1 is for semianthracites, and 16.5 is for low-rank coal.

Following partial empiric law concerning the depth effect on methane content of coal seams has been formulated basing upon simultaneous analysis of Hilt-Skok's rule [10], and metamorphic methane content scale of G.D. Lydin:

- coal methane content experiences almost linear increase from maximum values of lignite to methane content of semianthracites χ_{PA} with

$$\mathrm{grad}\,\chi_{ky} = \frac{\chi_{PA} - \chi_b}{\Delta H}, gradient,$$

where $grad\chi_{ky}$ is coal gas content gradient; ΔH is thickness of coal rock mass enclosing black coal;

- maximum methane content zone is within semianthracite occurrence depth;

- decrease in coal methane content takes place within low-grade 10A÷11A anthracite occurrence; the process almost follows linear law with

$$\mathrm{grad}\,\chi_{A} = \frac{\chi_{PA} - 2}{M_A}, gradient,$$

where, M_A is low-grade (i.e. 10A and 11A) anthracite rock mass thickness; and - it has been determined that anticlinal folds are the zones of tectonic unloading as well as intensive degasification where methane content of coal decreases according to linear law. Mine statistic forecast method concerning methane content of coal seam supports the result reliability.

Mining and statistical method

Mining and statistical method has been improved for mines in the Central Donbass Region according to following strategy.

1. Parameters, effecting gas recovery of coal seams, have been systemized. They are specified as follows: q_l is relative methane content of a level, m^3/ton; q_s is natural gas recovery of a seam, m^3/ton; K_r is a share of methane release from rocks; n is the number of seams being mined; m_s is thickness of seams being mined, m; k is the number of unmined complementary rocks being overmined (undermined); m_i is thickness of unmined seams, m; h_{pn} is maximum distance from n^{th} seam being mined to complementary seams under which gas release from the latter may be considered as that being equal to zero, m; and h_i is a distance on a normal from the seam, being mined, to i^{th} complementary seam being undermined (overmined).

2. Residual gas release of the overmined (undermined) complementary seams has been determined

$$q_{oct} = q_s \frac{h_i}{h_{pn}}, \mathrm{m}^3/\mathrm{ton}.$$

3. Residual gas release of coal complementary seams in the context of two and more overminings (overworking) has been identified

$$q_{oct} = q_{пл} \prod_{i=1}^{i=j} \frac{h_i}{h_{pn}}, \mathrm{m}^3/\mathrm{ton},$$

where j – is the number of seams overmining or undermining complementary seams.

4. Gas balance equation of a level has been formed

$$q_l = \frac{q_s\left(\sum_{i=1}^{n} m_i + \sum_{i=1}^{k} m_i - \sum_{i=1}^{k} m_i \cdot \prod_{i=1}^{j} \frac{h_i}{h_{pn}}\right)}{\sum_{i=1}^{n} m_i} \cdot (1+K_{\Pi}), \text{m}^3/\text{ton}.$$

5. Natural gas recovery of coal seams, being out of overmining and undermining. Has been determined using the formula

$$q_s = \frac{q_l \sum_{i=1}^{n} m_i}{(1+K_{\Pi}) \cdot \left(\sum_{i=1}^{n} m_i + \sum_{i=1}^{k} m_i - \sum_{i=1}^{k} m_i \cdot \prod_{i=1}^{j} \frac{h_j}{h_{pn}}\right)}, \text{m}^3/\text{ton}.$$

Data of regularities concerning changes, taking place in gas content of levels, have been used to identify regularities of depth effect on gas recovery [11].

Computational analysis has helped obtain values of $q_{пл}$ parameter as well as natural gas content of coal seams in the context of CDR (table 1).

The following results have been obtained in elaboration of mining and statistical method by G.D. Lydin [11]:

Application boundaries for linear law of depth effect on methane recovery of coal seams (i.e. lower boundary of lean coal occurrence) have been determined;

Identify method of analytical gas recovery has been improved while determining residual gas recovery of over-and undermined complementary seams taking into consideration their thickness, slope angle, and roof control method; and

It has been specified that actual contribution of rocks to gas balance of production units is four times more in comparison with traditional method.

Semi-empirical method

Semi-empirical method, intended to determine methane content of coal seams, consists of two parts: theoretical part, i.e. Langmuir equation, and empirical one, i.e. mining and statistical methods to characterize such physical parameters of the Earth's crust as temperature, rock hardness, and gas pressure. In elaboration of available solutions, the method has been completed with the empirical law of Hilt-Skok [5, 4] concerning depth effect on coal grades as well as on volatile-matter content, and the determined regularities of depth effect:

- on rock temperature

$$\lg t = a + b \cdot \lg H$$

where a and b are empirical coefficients taking corresponding values listed in Table 2.

Table 1 - Parameters of mining and statistical method

Indices	Specifications	Mine										
		8a				K. Marx			1-2 Krasny Oktiabr			
		Level, m										
		427/521	521/631	631/750	750/870	375/500	500/625	625/750	320/440	440/560	560/680	680/800
Depth of gas weathering zone, m	H_0	130				150			150			
Degree of methane content of mine workings, m/(m³/ton)	α	29-30				29			22-24			
Average mining depth, m	H_{mid}	474	576	690	810	437	562	688	380	500	620	740
Average actual methane content of mine workings in the context of a level, m³/ton	$q_{l.\,f.}$	12.7	17.5	-	-	14.5	-	-	13.3	18.6	-	-
Average analytical relative methane content of mine workings in the context of a level, m³/ton	$q_{l.\,c.}$	14.8	17.4	21.3	24.4	13.2	16.6	20.9	12.7	17.9	23.4	29.8
Analytical relative methane recovery of mine workings of certain coal seams, m³/ton	q_0	10.1	12.0	14.9	16.7	9.0	11.0	13.5	8.5	11.2	14.0	17.0
Residual methane contents of coal brought to grass, m³/ton of dry ash-free rock mass	χ_0	4.0				4.0			4.0			
Natural methane content, m³/ton of dry ash-free rock mass	χ	14.1	16.0	18.4	20.7	13.0	15.0	17.5	12.5	15.2	18.0	21.0
Gradient	$grad\,\chi$	0.0194				0.018			0.0236			

Table 2 - Empirical coefficients *a* and *b*.

Mines of the Associations	Empirical coefficients	
	a	*b*
Dzerzinskugol SE	0.17	0.57
Ordzhonikidzeugol SE	0.41	0.64
Artemugol SE	0.19	0.57

- on the degree of methane natural pressure

$$a^g = a - b \cdot V^{daf}$$

where V^{daf} is volatile-matter yield; *a*, and *b* are empirical coefficients (Table 3).

Table 3 - Empirical coefficients *a* and *b*, volatile-matter content

Volatile-matter content	Coefficients	
	a	*b*
Less than 21%	0.40	0.0013
More than 21%	0.23	0.0050

- on geothermal degree

$$a = 33 \cdot (0{,}43 + 0{,}57 \cdot \frac{\sigma}{100})$$

where α_i is geothermal degree, m/°C; σ is average value of sandstone crushing strength.

$$\sigma = 205 - 3.2 V_{mid}^{daf}, \text{ MPa;}$$

where V_{mid}^{daf} are average values of volatile-matter content in the context of coal seams of a mine field.

$$V_{mid}^{daf} = 0{,}5 \cdot (V_{up}^{daf} + V_{un}^{daf}), \%;$$

where V_{up}^{daf} V_{un}^{daf} are volatile-matter content relative to upper layer of Gorlovka formation, and under layer of Kamenskaia formation, %.

The study which has been done (points 2 and 3) has been implemented widely in the projects aimed at the development of new levels in thirty mines of the Central Donbass Region. That prevented from early reconstruction of ventilation systems in thirty mines by way of substituting available exhausting fans FC-31,5 м for more powerful FCB-4,5.

According to Clause 1, methane reserves in coal-methane Donbass deposits have been estimated [12].

Conclusions.

1. The generalization of published data and file materials related to methane content of mine workings, methane content and gas recovery of coal seams has been done.

2. Empirical methods of forecasting methane content (geological and statistical, mining and statistical, and semi-empirical) have been improved through integrated consideration of depth, tectonics, metamorphism, gas pressure, temperature, and rock hardness effect on the methane content value of coal seams.

3. Dneprogiproshakht Institute has applied the results of the given research work while developing thirty new levels; moreover, the findings may be applied while designing mine ventilation projects, and while estimating methane reserves in the context of coal deposits.

REFERENCES

1. Kravtsov A.I. (1979), *Gazonosnost ugolnykh basseynov i mestorozhdeniy SSSR. T. 1. Ugolnye basseyny i mestorozhdeniya evropeyskoy chasti SSSR* [Gas content of coal fields and deposits in the USSR: set of three volumes. Vol. 1. Coal fields and deposits of the European SU], Nedra, Moscow, SU.

2. Kravtsov A..I. (1979), *Gazonosnost ugolnykh basseynov i mestorozhdeniy SSSR. T. 2. Ugolnye basseyny i mestorozhdeniya Sibiri, Kazakhstana I Dalnego Vostoka* [Gas content of coal fields and deposits in the USSR: set of three volumes. Vol. 2. Coal fields and deposits in Siberia, Kazakhstan, and Far East], Nedra,Moscow: SU.

3. Kravtsov A.I. (1980), *Gazonosnost ugolnykh basseynov i mestorozhdeniy SSSR. T. 3. Genezis I zakonomernosti raspredeleniya prirodnykh gazov ugolnykh basseynov I mestorozhdeniy SSSR* [Gas content of coal fields and deposits in the USSR: set of three volumes. Vol. 3. Genesis and regularities concerning distribution of natural gases of coal fields and deposits in the USSR], Nedra, Moscow, SU.

4. Bulat A.F. (1998), "Developing mine methane industry in the context of Ukrainian fuel and energy complex", *Geo-Technical Mechanics*, no. 10, pp. 3-8.

5. Pivnyak G.G., Bondarenko V.I. and Razumny Yu.T. (2005), "Energy and Ecology of mine methane", *Geo-Technical Mechanics*, no. 53, pp. 8.

6. Griadushchiy, V.A., Maidukov, V.L. and Pivnyak, G.G. (2008). Coal deposits of Ukraine as a source of hydrocarbonic rock mass, *Ugol Ukrainy*, no. 4, pp. 3-5.

7. Bulat A.F. (2005). On the prospects of Ukrainian industry to extract methane from coal deposits, *Rock Mechanics: Interdepartmental collection of scientific papers*, Dnepropetrovsk: RMI of the NAS of Ukraine, no. 32, pp. 3-9.

8. Antsiferov A.V., Golubev A.A. and Kanin V.A. (2009), *Gazonosnost i resursy metana ugolnykh basseynov Ukrainy. T. 1. Geologiya i gazonosnost zapadnogo, yugo-zapadnogo iyuzhnogo Donbassa* [Gas content and methane reserves in the context of Ukrainian coal fields: monograph: set of three volumes. Vol. 1. Geology and gas content of Western, South-Western, and Southern Donbass], Veber, Donetsk, UA.

9. Antsiferov A.V., Golubev A.A. and Kanin V.A. (2010), *Gazonosnost i resursy metana ugolnykh basseynov Ukrainy. T. 2. Uglegazovye i gazovye mestorozhdeniya Severo-Vostochnogo Donbassa, DDV i Lvovsko-Volynskogo Basseyna* [Gas content and methane reserves in the context of Ukrainian coal fields: monograph: set of three volumes. Vol. 2. Coal-gas and gas deposits of North-Western Donbass, DDD, and Lvov-Volyn coal field], Veber, Donetsk, UA.

10. Skok V.I. (1965), "Metamorphism sources of mineral coal, and practices to classify its types", *Geology of Siberian and Far Eastern coal*, Nauka, Moscow, pp.27-40.

11. Lidin G.D. and Airuni A.T. (1963), *Gazoobilnost kamennougolnykh shakht SSSR* [Gas content of coal mines in the USSR], AN SSSR, Moscow, vol. 3, SU.

12. Sheiko A.V. (2018), "Method to estimate methane reserves in the context of rock mass of Donetsk coal field", Geo-Technical Mechanics, no. 137, pp. 180-190.

СПИСОК ЛІТЕРАТУРИ

1. Газоносность угольных бассейнов и месторождений СССР. Т.1. Угольные бассейны и месторождения европейской части СССР / Под ред. А.И. Кравцова. М.: Недра, 1979. 627 с.

2. Газоносность угольных бассейнов и месторождений СССР. Т. 2. Угольные бассейны и месторождения Сибири, Казахстана и Дальнего Востока / Под ред. А.И. Кравцова. М.: Недра, 1979. 454 с.

3. Газоносность угольных бассейнов и месторождений СССР. Т. 3. Генезис и закономерности распределения природных газов угольных бассейнов и месторождений СССР / Под ред. А. И. Кравцова. М.: Недра, 1980. 218 с.

4. Булат А.Ф. Создание индустрии шахтного метана в топливно-энергетическом комплексе Украины // Геотехническая механика: межвед. сб. научн. тр. / ИГТМ НАН Украины. Днепропетровск, 1998. Вып. 10. С. 3-8.

5. Пивняк Г.Г., Бондаренко В.И., Разумній Ю.Т. Энергетика и экология шахтного метана // Геотехническая механика: межвед. сб. научн. тр. / ИГТМ НАН Украины. Днепропетровск, 2005. Вып. 53. С. 8.

6. Грядущий, Б.А., Майдуков В.Л., Пивняк Г.Г. Угольные месторождения Украины как источник углеводородного массива // Уголь Украины. 2008. № 4. С. 3-5.

7. Булат А.Ф. О перспективах развития в Украине отрасли по извлечению метана угольных месторождений // Геотехническая механика: межвед. сб. научн. тр. / ИГТМ НАН Украины. Днепропетровск, 2002. Вып. 32. С. 3-9.

8. Анциферов А.В., Голубев А.А., Канин В.А. [и др.] Газоносность и ресурсы метана угольных бассейнов Украины: монография в 3-х т. Т. 1. Геология и газоносность западного, юго-западного и южного Донбасса Донецк, 2009. 449 с.

9. Анциферов А.В., Голубев А.А., Канин В.А. [и др.].Газоносность и ресурсы метана угольных бассейнов Украины: монография в 3-х т. Т. 2. Углегазовые и газовые месторождения Северо-Восточного Донбасса, ДДВ и Львовско-Волынского бассейна. Донецк: Вебер, 2010. 478 с.

10. Скок В.И. Причины метаморфизма ископаемых углей и опят классификации основный его типов // Геология углей Сибири и Дальнего Востока. М.: Наука, 1965. С.27-40.

11. Газообильность каменноугольных шахт СССР / Под ред. Г.Д. Лидина, А.Т. Айруни. М.: АН СССР, 1963. Т. 3. 223 с.

12. Шейко А.В. Метод определения запасов метана в углепородном массиве Донецкого бассейна // Геотехническая механика: межвед. сб. научн. тр. / ИГТМ НАН Украины. Днепр, 2005. №137. с. 180-190.

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Аннотация. Проблема определения метаноносности угольных пластов активно решалась в 60-80 годах прошлого столетия в связи с необходимостью повышения надежности проектирования систем газовой безопасности шахт. В настоящее время шахтный метан рассматривается как нетрадиционное вещество энергетической отрасли и в плане повышения безопасности, экологичности и технико-экономической эффективности действующих шахт. Поэтому решение задач надежности определения газоносности угольных месторождений снова актуализировалось. Работа относится к области газовой безопасности шахт и оценке запасов метана в метаноугольных месторождениях. Обобщены литературные и фондовые данные, а также усовершенствованы эмпирические методы определения метаноносности угольных пластов (геологостатистичсекий, горностатистический, полуэмперический). Установлено влияние тектонических структур угольных месторождений на относительную метаноносность. Уточнена закономерность влияния глубины на метаноносность угольных пластов. Усовершенствован горностатистический метод прогноза газоотдачи учетом закономерности влияния глубины, угла падения пород, мощности пластов и способов управления горным давлением на газоотдачу угольных пластов. Дана количественная оценка доли метановыделений из горных пород в газовом балансе добычного участка. Усовершенствован полуэмпирический метод прогноза метаноносности угольных пластов путем учета закона Хильта-Сака и установленных закономерностей влияния разгрузки, глубины и прочности пород на термобарические условия, предопределяющие газоносность угольных пластов. Результаты исследований внедрены в проекты института «Днепрогипрошахт». Доказательная часть усовершенствованных методов приведена в научных отчета институтов ИГТМ им. Полякова НАН Украины и «Днепрогипрошахт».

Ключевые слова: эмпирио-статистические методы, прогноз, метаноносность, угольный пласт, газовая эмиссия из угольных пластов.

Анотація. Проблема визначення метаноносності вугільних пластів активно розв'язувалася у 60-80 роках минулого сторіччя у зв'язку з необхідністю підвищення надійності проектування систем газової безпеки шахт. У даний час шахтний метан розглядається як нетрадиційна речовина енергетичної галузі і у плані підвищення безпеки, екологічності і техніко-економічної ефективності діючих шахт. Тому вирішення задач надійності визначення газоносності вугільних родовищ знову актуалізувалося. Робота відноситься до області газової безпеки шахт і оцінки запасів метану у метановугільних родовищах. Узагальнено літературні і фондові дані, а також вдосконалено емпіричні методи визначення метаноносності вугільних пластів (геологостатистичний, гірничостатистичний, напівемпіричний). Встановлено вплив тектонічних структур вугільних родовищ на відносну метаноносність. Уточнено закономірність впливу глибини на метаноносність вугільних пластів. Вдосконалено гірничостатистичний метод прогнозу газовіддачі врахуванням закономірності впливу глибини, кута падіння порід, потужності пластів і способів управління гірським тиском на газовіддачу вугільних пластів. Дана кількісна оцінка частки метановиділень з гірничих порід у газовому балансі видобувної ділянки. Вдосконалено напівемпіричний метод прогнозу метаноносності вугільних пластів шляхом врахування закону Хильта-Сака і встановлених закономірностей впливу розвантаження, глибини і міцності порід на термобаричні умови, що зумовлюють газоносність вугільних пластів. Результати досліджень упроваджено в проекти інституту «Дніпродіпрошахт». Доказову частину вдосконалених методів приведено у наукових звітах ІГТМ ім. М.С. Полякова НАН України і «Дніпродіпрошахт».

Ключові слова: емпіріо-статистичні методи, прогноз, метаноносність, вугільний пласт, газова емісія з вугільних пластів.

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