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REVISITING POSSIBILITY TO CROSS THE DISJUNCTIVE GEOLOGICAL FAULTS WITH UNDERGROUND GASIFIER

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ДО ПИТАННЯ ПЕРЕХОДУ ДИЗЮНКТИВНИХ ГЕОЛОГІЧНИХ ПОРУШЕНЬ ПІДЗЕМНИМ ГАЗОГЕНЕРАТОРОМ

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ABSTRACT

Purpose. To justify the opportunities to cross the disjunctive geological faults without full coal seam fracturing by underground gasifier, basing on the established time dependencies of underground gasifier output to an effective gasification regime applying the technology of borehole underground coal gasification.

Methods. The changing dependency of time when the underground gasifier reaches the regime of stabilization during underground coal gasification was found with a laboratory experimental unit.

Findings. The dependencies of fault plane amplitude in geological fault on the distance at which the gasifier reaches the regime of stabilization on the total output of combustible gases and their heating value were received. The change of the dependency of the coefficient of gasification enhancement, which is influenced by the thermochemical rate processes in reaction channel of the underground gasifier, is presented. The approach to transfer the results of the experimental investigation in natural conditions based on geometric and time simplifications was offered. The results of the research will allow adjusting the calculation of material and heat balance of the gasification process to determine the optimal qualitative and quantitative composition of injected air.

Originality. The time of underground gasifier reaching the regime of stabilization is determined by the rate of non-fracturing of a coal seam and regulated by the reaction channel advance and balanced supply of reagents blast.

Practical implications. The results of the experimental investigations are precise enough for practical application. They can be used to determine the output parameters allowing the process to reach the regime of stabilization during underground coal gasification. It gives the possibility to expand the use of underground coal gasification technology in geological fracturing zone and can be potentially involved in mine development of substandard coal reserves for energy and chemical generator gas production, chemicals and heat manufacture.

Keywords: *borehole underground coal gasification, in situ gasifier, rock mass, combustion face, chemical balance*

1. INTRODUCTION

Coal is the main fossil fuels used in power generation. According to the World Energy Resources 2013 on average 60.5% of global substandard coal reserves located in difficult mine and geological conditions, including the geological fracturing zones development of which would allow to increase the time of its consumption due to additional production and integrated use of the following 40 – 60 years. International and local experience shows that traditional coal mining in areas of geological fracturing is unviable because of the high cost of coal produced, low labor safety of miners and gas-dynamic phenomena that occur near the affected zones (Daggupati et al., 2010).

The concentration of coal seams in difficult mining and geological conditions at a considerable depth requires a comprehensive review of development opportunities. There is a need to develop alternative technology of extraction based on scientific investigation, consistent with the modern development of science and technology is cost-effective and environmentally safety

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Примечание [V7]: In INTRODUCTION authors should give:
- state of the art;
- a short analysis of the resent research and publications;
- unsolved aspects of the problem.

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Примечание [V9]: Acronym must be described and most importantly – belong to Clean Coal Technology. Such technology is underground coal gasification (UCG). Underground coal gasification is a promising option for the future use of un-worked coal. UCG permits coal to be gasified in situ within the coal seam, via a matrix of wells. The coal is ignited and air is injected underground to sustain a fire, which is essentially used to "mine" the coal and produce a combustible synthetic gas which can be used for industrial heating, power generation or the manufacture of hydrogen, synthetic natural gas or diesel fuel

For the conditions of Ukrainian energy and power sector, the research and justification the possibility of alternative mining technologies are essential. Substantial deposits of coal can be converted to generators gas turn-on commercially reasonable level, to solve problems of providing specific kind of energy and political aspects of the energy security (Bhutto, Bazmi & Zahedi, 2013).

An analysis of the recent research and publications. Breakthrough over the last decades in the field of underground coal gasification was obtained thanks to the strong interest in the development of alternative technologies of coal mining, due to the ever increasing demand and fuel price. On the issue of development and implementation the environmentally friendly technology of underground coal gasification of coal seams worked in more than one generation of local and foreign scholars (Falshtyns'kyy, Dychkovs'kyy, Lozyns'kyy & Saik, 2016).

Particular attention in this question deserves the works of V.I. Bondarenko, H.I. Hajko, R.O. Dychkovskyi, V.N. Kazak, O.V. Kolokolov, H.V. Orlov, I.A. Sadovenko, P.V. Scafa, Ju.V. Stefanyk, M.M. Tabachenko, V.S. Falshtynskyi, L. Yang, G. Perkins, S. Daggupati, and scientific departments of companies "Linc Energy", "Carbon Energy", "Cougar Energy", "Wildhorse Energy" (Australia), "Ergo Energy" (Canada), "Lawrence Livermore National Laboratory", "Carbon County" (USA), "ENN Coal Gasification Mining Corporation", "Xinwen Coal Industry Group" (China) and others.

The possibility of coal seams gasification with a large number of small-amplitude geological faults without coal seam fracturing, determine the minimum distance between faults, unconsumed coal left by the faults of various types; impact the stability of wells near geological faults, etc., currently is poorly understood.

Thus, the existing technologies of underground coal gasification process in the area of small-amplitude geological faults not sufficiently reflect the latest achievements of science and technology. Based on the problems associated with cross the disjunctive geological faults, it is clear that the study of new methods for the coal seams extraction in difficult geological conditions is now an urgent task not only for Ukraine but other countries around the world.

2. THE MAIN PART OF THE ARTICLE

The investigations on the laboratory model explain the need for a thorough examination of possible transition disjunctive geological dislocation without full coal seam fracturing at different values of displacement amplitude and also to receipt the initial data for development the methods for coal seam gasification in natural conditions (Yang, Zhang, Liu, Yu & Zhang, 2008) .

The experimental laboratory unit is projected and patented in the department of underground mining of National Mining University and built by PJSC "Neftemash" at sponsorship by the department of education and science of Ukraine. Installed and geared-up after the assistance of technical services of Donetsk electrical plant "Donetsksteel" and situated on the plant territory.

The processes occurring in the real underground conditions is extremely difficult, so choose a universal theory that takes into account the comprehensiveness of the process by looking at the system of phase transitions is almost impossible. Accordingly, in practice, mostly often studies are conducted on the basis of significant factors that are crucial for a certain amount of time to process. Control of the gasification process on laboratory unit carried out by injected air from the first compressor through the pipeline system to the reaction channel. Air inject in oxidation zone where reaction behavior is carried out by exothermic chemical reaction release the heat in gasification channel. In reducing zone where reaction behavior is carried out by endothermic chemical reaction absorb the heat in gasification channel. That is why it is necessary to calculate heat and material balance for physical equilibrium velocity and kinetics of chemical reactions in underground gasifier.

Combined injected air supply in pulsating regime allowed in a short time pass the ignition regime and reaches the regime of stabilization. In oxidation zone the multiphase chemical reaction between oxygen, which has been supplying in the gasifier, and carbon (the main part of coal seam) provide heat generation to high enough temperature. Heat generation provides endothermic reaction behaviour of carbon dioxide (CO_2) recovery and water vapor decomposition (Yang, 2003).

The enhancement of the total process of carbon gasification theoretically depends both the rate of chemical reactions and the enhancement of injected air supply and extraction of gasification product. The role of these heterogenous factors depends on specific conditions of gasification process. The interactions of carbon with oxygen are formed oxide and carbon dioxide. At low temperatures, the rate of chemical reactions between carbon and oxygen is low, and the total rate of the process is determined by the speed of chemical reactions.

During the investigation the reagents of blast passing through three reaction zones formed generator gases comprised combustible mixture of CO, H_2 and CH_4. The proportion of these gases varied depending on the type of blowing and time from the beginning of the study. Generator gases move out along the direction of air flow. The concentration of generator gases that are presented on Figure 1 were measured by gas detectors "Gasboard 320 L" and "BX-170", that work in dynamic and manual mode (Perkins & Sahajwalla, 2006).

Since experimental studies of coal gasification include a coal ignition, followed by reaction channel formation in oxidation and reducing zone with a gradual transition to a stable regime of gasification process, on Figure 1 marked conventional division between these processes.

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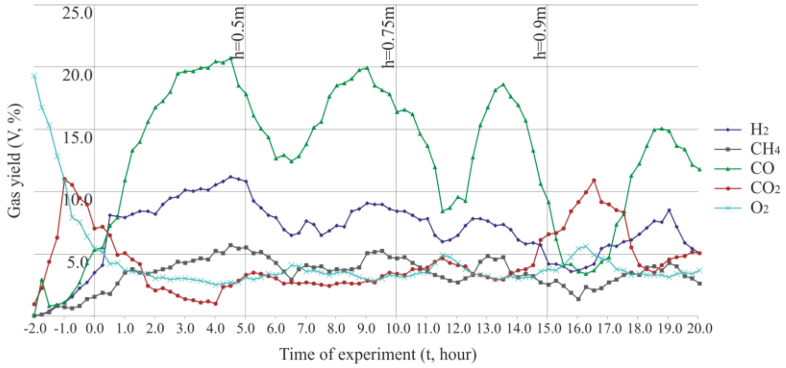

Figure 1. Generator gas output during experiment

After five hours of efficient gasification process was fixed a decrease in all indices of combustible gases, indicating the approaching of fault plane and disbalance of material and heat balance. This situation during experiment promote to the deployment of the experiment gasification process transfer to manual control mode. There was a gradual reduction of injected air supply in the zone of reaction channel to prevent formation the high-concentration of unreacted part of oxygen in the recovery zone. For the calculation of materially-thermal balance of BUCG, the special program was utilized. The calculation algorithm includes thermo chemical conversions of solid fuel into gas and condensed fluid in the conditions of elementary composition of coal seam.

After stabilization of gasification the process moved in planning mode of gasification. During experiment, with a certain step, such intermittent effect was observed three times. Ready for the development of such events has enabled early steps to predict the alarm appearance during experimental investigation. The ratio CO/CO_2 in generator gases depends on kinetic and hydrodynamic conditions of carbon combustion and significant effect not only on the process of gas production, but the intensity of oxygen consumption and correspondingly expansion of oxidation zone.

Throughout the experiment, there was a high concentration of CO in the generator gases with respect to CO_2, which is explained quite effective chemical reactions under high temperatures in an oxidation zone and a small amount of water vapor and gradual reduction of O_2 shows the number of balanced injected air blast supply. Exceptions are areas where was crossing of the fault plane. Here was a dramatic decrease the volume of combustible generator gases and smoky gas increase. This is especially true for transition zone III – IV in which on 16 hours 30 minutes from start the gasification the concentration of CO_2 reached to 10.5 – 1.3%, O_2 – 5.6%. The formation of so-called reduction of CO roughly coincides with the presence of geological faults, although there is some disagreement with the calculated parameters.

Analyzing the decrease in the concentration of CO, it should be noted that the so-called lowering the percentage content of carbon monoxide occur before displacement amplitude of disjunctive geological fault, because the gasification of coal seam is carried out not only in the length of the reaction channel. In the coal seam perpendicular to the reaction channel formed a chemical zone of oxidation, recovery and drying. Disturbance of these zones provide variation of material and heat balance, which in due course time degrades the output of combustible generator gases.

According to research results reduction of qualitative and quantitative composition of the generator gases resulted by varying the power of the coal seam, including the presence of disjunctive fault. Geological anomalies greatly influence to the redistribution of heat in the reaction channel of underground gasifier affecting the initial concentration of gas generator.

Making parallels between the obtained concentrations of combustible and non-combustible generator gases (Fig. 1) there is a substitution of some other. In the zone I and reduce the concentration of H_2, CH_4, CO started at 4 hours 45 minutes in the zone II – at 9 hours 15 minutes, while zone III – 13 hours 45 min from the beginning of gasification process on laboratory unit.

Confirmation the linear velocity of combustible face advance made it possible to analyze timing violations of crossing the geological fault by underground gasifier with access to effective regime of gasification on the total output of combustible generator gases and their heating value during the experiment (Fig. 2).

Definition the time when underground gasification processes reach the regime of stabilization requires phased implementation analysis of experimental data. First, this analysis was performed on the total output of generator gases.

It should be noted that the process of gasification is effective, and it is in a stable mode under the condition of the total output of combustible gases more than 25% or its heating value more than 4 MJ/m^3.

Because percentage volume fixation of generator gases occurred at intervals in 15 minutes, in this case, for a more precise definition of the moment when gasification process reaches the regime of stabilization take into account the total output of combustible gases $\overline{t_V}$ can be found by the following formula:

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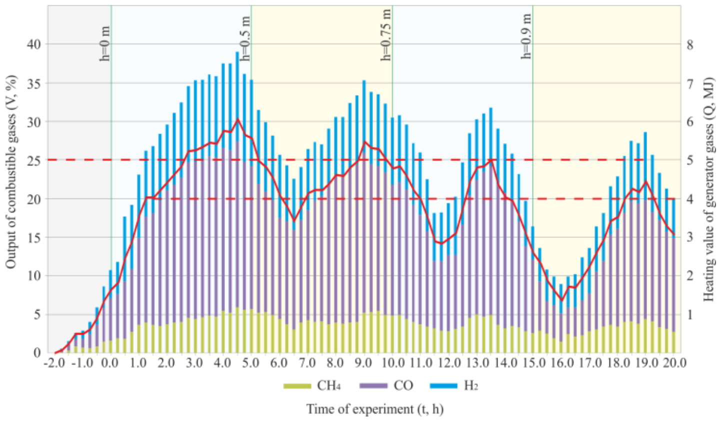

Figure 2. The total output of combustible generator gases and their heating value during the experiment

$$\overline{t_V} = \left[t_1 + \left(\frac{t_2 - t_1}{100} \right) \cdot \frac{25 - \sum C, at\ t_1}{\sum C, at\ t_2 - \sum C, at\ t_1} \cdot 100 \right] - t \quad , \quad (1)$$

where:

t_1 – nearest fixed time, where the total value of output combustible generator gases was $\geq 25\%$;

t_2 – nearest fixed time, where the total value of output combustible generator gases was $\geq 25\%$;

$\sum C$ – the total percentage content of combustible generator gases;

$t_з$ – estimated time of crossing the fault plane of disjunctive geological fault.

The next phase of the data analysis experiment was to determine the actual time when the gasification reach the regime of stabilization. That determination we should do including important parameter (1) such as heating value $\overline{t_Q}$ that was conducted by the following formula:

$$\overline{t_Q} = \left[t_1 + \left(\frac{t_2 - t_1}{100} \right) \cdot \frac{4 - Q, at\ t_1}{Q, at\ t_2 - Q, at\ t_1} \cdot 100 \right] - t_з , \quad (2)$$

where:

t_1 – nearest fixed time where the heating value of combustible generator gases was ≤ 4 MJ/m^3;

t_2 – nearest fixed time where the heating value of combustible generator gases was ≥ 4 MJ/m^3.

The heating value of generator gases $Q_{g.g}$ is equal to the heating value of all combustible gases: CO, H_2, CH_4. For determine the heating value of generator gases we can use the next formula:

$$Q_{g.g} = \frac{127.7 \cdot CO + 108 \cdot H_2 + 356 \cdot CH_4}{1000} , \quad (3)$$

where:

CO, H_2, CH_4 – the percentage of the corresponding generator gases.

In the table 1 are shown basic parameters, which took place for the calculation $\overline{t_V}$ and $\overline{t_Q}$ for displacement amplitude considered at a specified time.

Table 1. Basic parameters and calculation results

Displacement amplitude. m	Time. hour		Gas production, %				Heating value of generator gases. MJ/m^3	The regime of stabilization of underground gasifier. hour	
h			H_2^*	CH_4^*	CO^*	Σ	$Q_{g.g}$	$\overline{t_V}$	$\overline{t_Q}$
0	t_1	1.00	8.2	3.6	11.3	23.1	3.61	1.09	1.13
	t_2	1.25	8.5	3.9	13.8	26.2	4.07		
0.5	t_1	6.75	6.9	3.9	13.3	24.1	3.83	1.67	1.72
	t_2	7.00	7.9	4.2	14.3	26.4	4.17		
0.75	t_1	12.50	8.1	3.4	13.2	24.7	3.77	2.31	2.20
	t_2	12.75	8.1	4.5	15.9	28.5	4.51		
0.9	t_1	18.00	6.8	3.4	12.7	22.9	3.57	3.07	3.14
	t_2	18.25	7.3	4.0	14.2	25.5	4.03		

* Combustible gases.

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Type all text in tables in small type – 9 points.

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In tables the following reference marks should be used: *, **, etc., and the actual footnotes set directly underneath the table.

Due to experimental studies were conducted with account the coefficient of geometric similarity. Then transfer results in natural conditions should execute the inverse problem. The essence of which is described below.

At calculated the combustion face speed advance $V_g = 9$ cm/hour. which with a high probability (as we can see based on the results of the study) was observed. coal seam ($l_{g.g}^{m} = 180$ cm) gasified during 20 hours.

Take into account that this model correspond the length of the gasifier in the nature $l_{g.g}^{n} = 36$ m. than the time of gasification of extraction pillar will make $t_y = 400$ hours at a similar rate of combustible face advance.

For making the analysis of experimental studies more ease we can made the calculation of coal gasification advance to compare time of gasification in gasifier model t_x and gasifier in nature t_y and t_z.

Here are the temporal and geometric transformations in the system of equations:

$$\begin{cases} l_{g.g}^{m} \to t_x, \ \ at\ V_1 \\ l_{g.g}^{n} \to t_y = \dfrac{l_{g.g}^{n}}{V_1}, \ \ at\ V_1, \\ l_{g.g}^{n} \to t_z, \ \ at\ V_2 \end{cases} \qquad (4)$$

where: $t_z = t_x \cdot \dfrac{day}{hour}$. Than $V_2 = \dfrac{l_{g.g}^{n}}{t_z}$.

In this system of equations temporal and geometric frames are calculated from variables to enable comparison of numerical values x and z. After calculation. we obtain the speed of combustion face advance in nature 7.5 cm/hour. and the total time of coal seam gasification $t_z = 20$ days.

Conclusion concerning observance the similarity of nature and the model give the calculation of homochronicity criterion that is constant temporal similarities in the processes. Also was considered invariant and simplex of similarity in thermochemical processes.

Now we can get dependence of the fault plane amplitude on the distance at which the underground experimental gasifier reach the regime of stabilization on the base of generator gases production and heating value of generator gases (Fig. 3).

On Figure 3 the hourly value when underground coal gasification reach the regime of stabilization. were comprised with the distance from the fault plane by the following simplification:

$$l_{g.g}^{m} \to t_x = \ l_{g.g}^{n} \to t_z \quad \Leftrightarrow \quad t_x = t_z. \qquad (5)$$

Accordingly: $l_{\overline{t_V}} = \dfrac{l_{g.g}^{n}}{t_z} \cdot \overline{t_V}$. And $l_{\overline{t_Q}} = \dfrac{l_{g.g}^{n}}{t_z} \cdot \overline{t_Q}$.

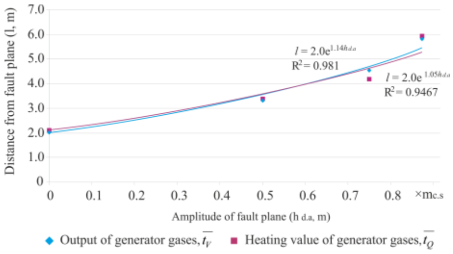

Figure 3. The dependence of the fault plane amplitude on the distance at which the gasifier reach the regime of stabilization

Fine precision of received results (Fig. 3) allows us to determine the distance from fault plane at which gasification process reach the regime of stabilization:

$$l = 1{,}9e^{1{,}1 \cdot h_{d.a}}, \qquad (6)$$

where:

$h_{d.a}$ – displacement amplitude of fault.

The undoubted is that the time of passing some distance by underground gasifier can be corrected by speed advance of combustion face. Thus. the rate of gasification enhancement. characterize the change in speed advance of a combustion face. Speed advance depends on the balanced quantity of injected air.

After enhancement of coal seam gasification we have an opportunity for a shorter time reach the regime of stabilization; however these action require additional technical implementations in the gasifier operation.

3. CONCLUSIONS

Reduce the percentage concentration of combustible generator gases appear ahead of disjunctive fault plane of the geological fault. because the break down an altogether chemical zone in coal seam perpendicular to the reaction channel.

Time t at which underground gasifier reach the regime of stabilization. that are determined by the total output of generator gases and the heating value of generator gases crossing disjunctive geologic fault with the amplitude up to 0.9 of coal seam thickness at an exponential dependence depends on the displacement amplitude $h_{d.a}$ and the speed of combustion face advance V_g.

The enhancement of the geological fault crossing zones depend on balanced supply of injected reagents. respectively. take into account heterogenic geometry of coal seam. it is necessary to conduct additional calculation of material and heat balance and make manual mode of gasification process.

Effective in the further researches is to conduct similar studies using computer simulation to confirm or refute the results of experimental studies on laboratory unit. In addition. efforts should pray to conduct a detailed study of coal seams abandon after the mining. where traditional mining is inefficient.

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Примечание [V25]: Conclusions should state concisely the most important propositions of the paper as well as the author's views of the practical implications of the results.

ACKNOWLEDGMENTS

The present study would have been impossible without support from the ISF grants RLY000 and RLY300 (A.Y.B.). Additional support was obtained from the Thule Institute (University of Oulu. Finland). Kola Science Center. Russia. RFFI grant 95-05-16503 (Y.P.M.). and the International Renaissance Foundation. Dnepropetrovsk. Ukraine (S.S.G). We express our sincere gratitude to M. Tarkian (University of Hamburg) and Y.N. Neradovsky (Kola Science Center) for the reflectance and microhardness data. and to A.J. Criddle for his valuable improvements to thefirst version of this manuscript. We greatly appreciate constructive reviews from L.A. Groat and C.J. Stanley are thanked for their assistance with the electron microprobe analyses.

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ABSTRACT (IN UKRAINIAN)

Мета. Обгрунтування можливості переходу диз'юнктивних геологічних порушень без розриву суцільності вугільного пласта підземним газогенератором, виходячи із встановлених залежностей зміни часу виходу підземного газогенератора на ефективний режим вигазовування при застосуванні технології свердловинної підземної газифікації вугілля.

Методика. Стендовими експериментальними дослідженнями встановлені залежності зміни часу виходу підземного газогенератора на ефективний режим вигазовування при підземній газифікації вугілля.

Результати. Отримані залежності впливу амплітуди зміщувача геологічного порушення на відстань при якій газогенератор переходить на ефективний режим вигазовування по сумарному виходу горючих генераторних газів та їх теплоти згорання. Представлена залежність зміни коефіцієнта інтенсифікації вигазовування, що залежить від кінетики протікання термохімічних реакцій в реакційному каналі підземного газогенератора. Запропонований підхід до перенесення результатів стендових експериментальних досліджень в натурні умови на основі геометричних та часових спрощень. Результати досліджень дадуть змогу внести корективи в розрахунок матеріально-теплового балансу процесу газифікації для визначення оптимального якісного та кількісного складу дуттьової суміші.

Наукова новизна. Час виходу підземного газогенератора на ефективний режим вигазовування визначається ступенем нерозривності вугільного пласта та регулюється швидкістю посування вогневого вибою і збалансованою подачею реагентів дуття.

Практична значимість. Отримані результати стендових експериментальних досліджень із достатньою для практичного застосування точністю можуть використовуватися для визначення параметрів виходу підземного газогенератора на ефективний режим вигазовування, дають можливість розширити область застосування технології свердловинної підземної газифікації вугілля в зонах геологічної порушенності гірського масиву та в перспективі залучати до відпрацювання неконденційні поклади кам'яного вугілля для отриманню енергетичного та хімічного генераторного газу, хімічних продуктів та теплової енергії.

Ключові слова: *стендові дослідження, диз'юнктивні геологічні порушення, підземний газогенератор*

ABSTRACT (IN RUSSIAN)

Цель. Обоснование возможности перехода дизъюнктивных геологических нарушений без разрыва сплошности угольного пласта подземным газогенератором, исходя из установленных зависимостей изменения времени выхода подземного газогенератора на эффективный режим вигазовывания при применении технологии скважинной подземной газификации угля.

Методика. Стендовыми экспериментальными исследованиями установлены зависимости изменения времени выхода подземного газогенератора на эффективный режим вигазовывания при подземной газификации угля.

Результаты. Полученные зависимости влияния амплитуды сместителя геологического нарушения на расстояние, при котором газогенератор переходит на эффективный режим вигазовывания по суммарному выходу горючих генераторных газов и их теплоты сгорания. Представлена зависимость изменения коэффициента интенсификации вигазовывания который зависит от кинетики протекания термохимических реакций в реакционной канале подземного газогенератора. Предложен подход к переносу результатов стендовых экспериментальных исследований в натурные условия на основе геометрических и временных упрощений. Результаты иссле-

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дований позволят внести коррективы в расчет материально-теплового баланса процесса газификации для определения оптимального качественного и количественного состава дутьевой смеси.

Научная новизна. Время выхода подземного газогенератора на эффективный режим вигазовывания определяется степенью неразрывности пласта и регулируется скоростью подвигания огневого забоя и сбалансированной подачей реагентов дутья.

Практическая значимость. Полученные результаты стендовых экспериментальных исследований, с достаточной для практического применения точностью, могут использоваться для определения параметров выхода подземного газогенератора на эффективный режим вигазовування, дают возможность расширить область применения технологии скважинной подземной газификации угля в зонах геологического нарушения горного массива и в перспективе привлекать к отработке некондиционные залежи каменного угля для получения энергетического и химического генераторного газа, химических продуктов и тепловой энергии.

Ключевые слова: *стендовые исследования, дизъюнктивные геологические нарушения, подземный газогенератор*

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