DNIPRO UNIVERSITY of TECHNOLOGY 1899

Mining of Mineral Deposits
ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
Journal homepage http://mining.in.ua
Volume 12 (2018), Issue 2, pp. 68-75

UDC 622.273 https://doi.org/10.15407/mining12.02.068

INNOVATIVE ASPECTS OF UNDERGROUND COAL GASIFICATION TECHNOLOGY IN MINE CONDITIONS

V. Falshtynskyi[1], P. Saik[1*], V. Lozynskyi[1], R. Dychkovskyi[1], M. Petlovanyi[1]
[1]*Dnipro University of Technology, Dnipro, Ukraine*
**Corresponding author: e-mail saik.nmu@gmail.com, tel. +380638662636*

ABSTRACT

Purpose. Development of innovative approaches in technological and technical solutions improvement for coal seam gasification.

Methods. Carrying-out of native and world experience in the coal reserves development by underground gasification technology analysis, analytical studies on the heat and mass balance gasification process parameters determining and determination of the rock massif stress-deformed state around the gas gasifiers, and its technical and economic indicators operation.

Findings. The analytical calculations of the rocks stress-deformed state for the Western Donbas mines conditions have revealed that the maximum length of the gasification pillar should not be more than 580 m. The innovative technological schemes of gas gasifiers sites preparation work are proposed in two constructions: with roses and drill injected blast activators. The energy indicators of the gas gasifiers work, the period of release into the gasification mode during reverse operations and fuel gases discharge during different combustion face advance and the injected blast composition are determined. Introduction of gas gasifiers' constructions with drill injected blast activators are recommended for the numerous advantages.

Originality. The dependence of the gasification pillar length change on the technical and economic parameters of the gasification station operation was established; the dependence of the gasification operation on the gasification mode and exhaust gases discharge, depending on the injected blast composition and the rate of the combustion face advance.

Practical implications. The rational parameters of bed preparation at mine gasification, as well as energy and technological parameters of this process are substantiated. New technological schemes for coal reserves working out with gasification have been developed, which will allow additionally to use non-commercial and abandoned mine reserves and extend the mining enterprises duration.

Keywords: *underground coal gasification, combustion face, gasifier, exhaust gases, heat and mass balance*

1. INTRODUCTION

Today, proportion of coal in the energy industry of the country is 34.6%. According to the Ministry of Energy and coal-mining industry of Ukraine, the total volume of coal production in 2017 amounted to 34.9 million tons. Compared to 2016, its volume decreased by 14.6%. This situation is explained by the fact that the coal industry of the country is in a crisis condition due to a number of reasons: outdated and rundown mining equipment, high production costs, lack of significant investments in re-equipment of production, loss of human resources due to falling prestige, imperfection of Price and Fee Policy, depending on caloric value of coal product and market opacity (Kharlamova, Chernyak, & Nate, 2016; Gladii, 2017; Bondarenko, Svietkina, & Sai, 2017).

Mainly, the crisis is due to the presence of a large number of unprofitable, unproductive enterprises and the lack of facilities for mines remodelling that are promising for investment (Vivcharenko, 2012; Petenko & Maidukova, 2014; Borshchevska, 2015). Analyzing the coal production dynamics (Snihur, Malashkevych, & Vvedenska, 2016), it can be noted that the existing problems with the coal industry state were accompanied by the military-political problems in the country, associated with the occupation of the eastern territory part and get out of 85 state mines control, that is 60% of the mine fund, and by 2016 35 state and 22 private mines, resulting in a significant reduction in coal production.

Taking into account the complex situation in the fuel and energy sector of Ukraine's industry, it is necessary to change technological and technical solutions for the coal development fundamentally (Bondarenko, Griadushchiy, Dychkovskiy, Korz, & Koval, 2007). All these realities require comprehensive solution on the development and introduction of innovative technologies for coal extraction and processing at the site of its occurrence to obtain a hydrocarbon-chemical product. One of such technologies is borehole underground coal gasification (BUCG) (Falshtynskyi, Dychkovskyi, Saik, Lozynskyi, & Cabana, 2017).

The introduction of BUCG in colliery undertakings that have given out their existence or are in stagnation will allow the exploitation of mines to be prolonged by bringing coal reserves left behind for technical and environmental reasons (Wiatowski et al., 2015; Nieć, Sermet, Chećko, & Górecki, 2017). The BUCG technology provides the efficient gasification process adaptation to the mining system through the end-product variety and direction based on the market conditions, taking into account technical and mining-geological conditions dynamic change for the coal reserves deposit (Dubiński & Turek, 2016).

2. ANALYSIS OF TECHNOLOGY SOLUTIONS ON COAL GASIFICATION IN THE PLACE OF ITS OCCURRENCE

Today the native and world concept of BUCG technological schemes development is constantly being improved. Research program design on underground gasification of solid organic fuels is under development (Langan & Friggens, 1991; Yang, 2003; Li, Liang, & Liang, 2007; Blinderman, 2017). The main focus of these programs is to obtain high-quality combustible fuels, which, by their calorific value, is not inferior to natural gas. The peculiarity of the gasification process conducting is based on the suitability criteria of the coal reserves substantiation for gasification (Lozynskyi, Saik, Petlovanyi, Sai, & Malanchyk, 2018). These criteria influence the choice of preparation methods and coal reserves development systems by gasification technology.

The developed underground gasification technological schemes by the employees of the "National Mining University" have been substantiated by analytical studies, approved and corrected gas gasifier operating parameters in laboratory and industrial experiments for the mining and geological conditions of the Western Donbas formation and under the conditions of the experimental mine "Barbara" (Katowice, Poland). They fully ensure the efficiency of the gasification process (Falshtynskyy, Dychkovskyy, Lozynskyy, & Saik, 2012; Falshtyns'kyy, Dychkovs'kyy, Lozyns'kyy, & Saik, 2013).

Analysis of the situation with non-commercial and abandoned mine reserves showed that it is most expedient to use their technology for gasification in mine conditions (Wang, Wang, Feng, Rudolph, & Jiao, 2009; Mocek et al., 2016; Xin et al., 2017). The introduction of mine gasifiers requires the coal mining availability. In this case, the gasifiers preparation is carried out by horizontal, inclined wells from preliminary developments. Gasification channel formation is carried out with the bankette of preliminary development. The opening and preparation of mining reserves, which are not opened, is carried out from mining developments by semisteep horizontal wells in horizontal direction along the coal seam. Gasification channel formation between the wells is carried out by hydraulic fracturing or burning (Blinderman, Saulov, & Klimenko, 2008; Jiang, Chen, & Ali, 2017).

The main components that affect the allotment and/or its site preparation parameters to the mine underground gasification technology implementation are mining and geological conditions for the reserves occurrence and mining and technical factors for mining operations within the selected area (Lozynskyi, Dychkovskyi, Falshtynskyi, & Saik, 2015; Saik, Dychkovskyi, Lozynskyi, Malanchuk, & Malanchuk, 2016). The mine gasifier construction life, which is determined by the geomechanical factor, depends on rate of combustion face advance and the stress-deformed state of the rock massif around the gasifier (Dychkovskyi et al., 2018). In Table 1 on the example of the Stashkova mine (c_5 seam) the results of rocks lowering and stress at immediate mine roof bottom layer folding on the length of the extraction pillar of the gasifier are shown.

Table 1. Physical parameters of the bearing zone at immediate roof bottom layer folding on the length of the extraction pillar of the gasifier

Stress in the coal massif, MPa			Lowering the bottom layer of the roof, mm		Bottom layer of the roof shift, mm		Combustion face advance, m/day
G_c	G_t	G_{st}	over the combustion face	15 m from the combustion face	over the combustion face	15 m from the combustion face	
2.70	0.54	0.08	163.00	614.00	68.60	152.30	0.50
3.10	0.72	0.12	128.00	560.00	56.10	124.40	1.00
5.60	0.98	0.33	110.00	484.00	41.20	100.80	2.00

Analysis of the stress-deformed rocks state calculation results at the finite area of the gasifier when the velocity of combustion face advance changes, leads to a decrease in the bearing zone from 14.3 to 6.9 m and the increase in coal seam stresses from 2.7 to 5.6 MPa. Horizontal displacements vary in the range of 41.2 – 68.6 mm, with a strike slip towards the combustion face and the exploitation wells of the gasifier. Deformations in the coal seam along the exploitation wells in the bearing zone are within the range of 2.5 – 3.8 mm/m. It should be noted that the nature of such stress intensity and deformations does not affect the rock mass state around the wells adjacent to combustion face. This is due to the small size of combustion face at its length (≤ 60 m) and the presence of thermoelectromotive force around it, ensuring equal distribution of combustion face at the finite areas.

Analytical calculations, for the PJSC "DTEK Pavlohradvuhillia" conditions, found that the maximum length of the gasification pillar does not exceed 580 m. The combustion face length varies from 30 to 60 m, depending on the conditions of "rock massif – underground gasifier" system adaptation taking into account the geomechanical factor, technical and technological parameters of the gasifier equipment, methods of blast injection and exhaust gases flows grouping.

The economic efficiency of the given parameters of the gasifier extraction pillar length was confirmed on the basis of technical and economic construction indicators calculations and underground coal gasification station operation: investments, the number of workers, labor productivity, gas price cost, the payback period of investments.

The complexity of the gasification station chemical composite economic calculations is related to the cost and economic efficiency of the BUCG by-products processing (ballasting gases, chemical feedstock). This is due to significant fluctuations both in particular products rate scale of the chemical industry and in producing costs of various technological processes.

The area of the rational pillar length that is gasified during the gasification station operation, which consists of 4 to 6 mine gasifiers, is shown in Figure 1.

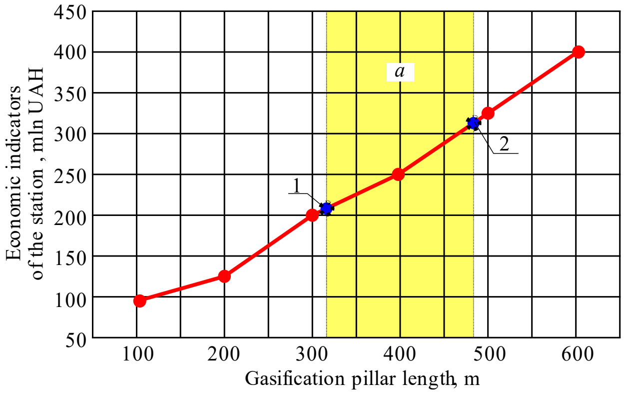

Figure 1. Change dependency in the gasification pillar length on the technical and economic indicators of the station: (a) area of rational gasification pillar length

The most suitable for comparison with BUCG is a method of coal processing by coking tendency. The experience of the coal coking technology developing, the use of chemical products obtained in the process can serve as a basis for chemical production technology creation based on underground coal gasification. In calculations, the overturn consists of two parts: the cost of gas produced and released to the consumer; the cost of heat energy generated by utilizing the heat of waste gases and sold to industrial enterprises and public utility companies.

Analysis of the dependency shown in Figure 1 indicates that the rational area of the mine gasifier length is from 320 to 480 m. Point *1*, shown in Figure 1, characterizes the minimum gasifier length, which allows covering the minimum costs for the construction and operation of the coal gasification station surface complex. Point *2* shows the maximum gasifier length based on analytical studies of the geomechanical factor.

3. TECHNOLOGICAL RECOMMENDATIONS FOR THE MINE GASIFIER OPERATION

The mine gasifier preparation is carried out in mine conditions from mining excavations by drilling horizontal exploitation wells along the coal seam. The technological scheme of the mine gasifier is shown in Figure 2.

The gasification channel of the gasifier *2* is formed from the airway bankette *18* between the air injection hole *4* and gas-conducting wells *5*. Its length is determined on the basis of gasification heat and mass balance indicators, the size of the exothermic reactions zone and the geomechanical parameters of the rock mass containing the gasifier. The flexible tubing with roses *6*, *7* in gasifier is carried out after the of exploitation wells preparation *4*, *5* on the haulage gate side *17*.

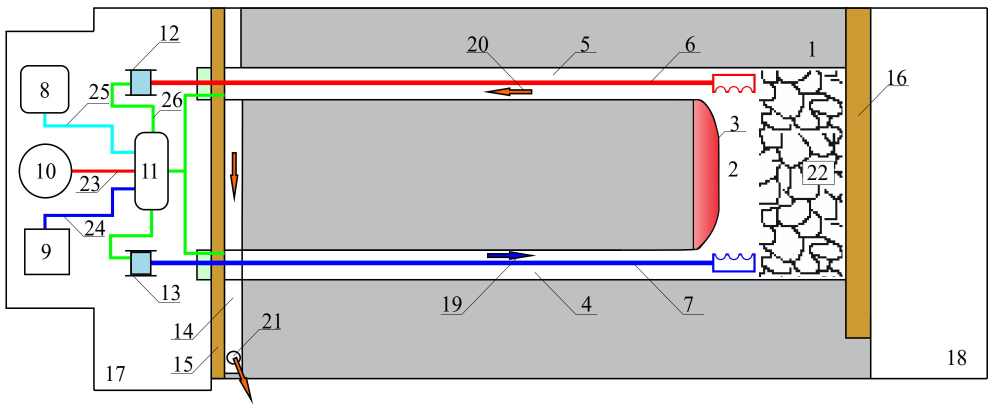

Figure 2. Technological scheme of the mine gasifier with roses: 1 – coal seam; 2 – gasification channel of the gasifier; 3 – combustion face; 4 – air injection hole; 5 – gas-conducting well; 6, 7 – flexible pipeline with rose; 8 – compressor for air blast supply; 9 – oxygen capacity; 10 – steam generator; 11 – fault plane dispenser of blast components; 12, 13 – a device for moving a flexible pipeline with roses; 14 – gas-conducting bankettes; 15 – heat-resistant phosphogypsum barrier of haulage gate; 16 – heat-resistant phosphogypsum barrier of airway; 17 – haulage gate; 18 – airway; 19 – the direction of air blast supply; 20 – direction of gasification products venting; 21 – vertical gas outlet well (connection with the surface cleaning complex and gasification products processing); 22 – gasification affected area; 23 – steam line; 24 – oxygen line; 25 – air line; 26 – blast pipeline

The gasification channel is separated from airway by a heat-resistant phosphogypsum barrier *16*, before its installation, on the connection between air injection hole with the gasification channel, wood chocks are carried out. The free space of the wood chocks is filled with pieces of coal.

The binary charge, as the main ignition element, serves as an ignition capsule of wood chocks. It is fed from the haulage gate side *17* through the air injection hole *4*. To provide additional activation of the coal seam ignition process, oxygen is supplied along the flexible pipeline *7* through the rose into the place of ignition.

The system of gasifiers development involves the use of flexible pipelines with an internal diameter of 28 cm and an external 33.5 cm in reels. For a stable supply of injected blast mixture to the combustion face source, a fault plane dispenser of blast components *11* is used. It provides continuous air injection through the main exploitation wells and flexible controlled pipelines while combustion face advance. The use of such an integrated air injection system ensures that the active blasting reagents (O_2, O_2 + CO, superheated steam) are fed and controlled by the combustion face of the gasification channel.

After coal seam ignition from the oxygen capacity *9* to the combustion face of the gasification channel oxidation zone, oxygen is fed along the flexible pipeline of the well *4* through the rose. Formation and further exploitation of the gasification channel oxidation zone is associated with the exothermic processes of thermochemical reactions. These reactions provide a stable kinetics of endothermic reactions in the reduction zone of the gasification channel. The length of the oxidation zone is 30 – 33% of the gasification channel length.

From the gas-conducting well *5* along the flexible pipeline *6* to the combustion face *23* of the reduction zone, superheated steam with a temperature of ≤ 125°C or water steam > 125°C, depending on the humidity of the rock mass and the water supply in the gasification channel *6*, is supplied with steam generator *10*. Quantitative steam supply indices in the reduction zone are calculated according to the heat and mass balance of the gasification process in order to obtain a technical or exhaust gas with high consumer qualities.

Controlled flexible pipelines with roses move along the combustion face with the help of trommels *12*, *13*. Exhaust gases *20* from the gasification channel along the gas-conducting well *5* are sent to the gas-conducting bankette *14* under the pressure, separated from haulage gate *17* with heat-resistant phosphogypsum barrier. Gasification products on a vertical gas-conducting well *21* are sent to underground gasification products purifying and processing surface complex.

The implementation of controllability of the gasification channel zones method by supplying the active injected blast components along a flexible pipeline through roses into the gasification channel selectively, according to the process direction, will ensure the technical exhaust gas output suitable for further thermal conversion to obtain a synthetic product or an energy gas according to the needs and hydrocarbon market condition.

Technological indices of a mine gasifier equipped with a flexible pipeline with roses at coal seam c_5 gasification (grade *G*) under the conditions of the Stashkova PJSC "DTEK Pavlohradvuhillia" mine are given in the Table 2.

Table 2. Technological indices of c_5 coal seam gasification

Type of injected blast	The number of gasified coal				Duration of pillar gasification, days	Output of combustible gases (H_2, CH_4, CO) during gasifier operation, m^3
	t/hour	t/day	t/year	t/during exploitation period		
Air	2.15	51.60	18834.00	16641.00	322.50	9.10
Steam	2.20	52.80	19272.00	16932.90	320.70	14.20
O_2 + steam	2.02	48.50	17703.00	16931.80	349.10	19.40
O_2 + CO_2 + steam	1.95	46.80	17082.00	16501.70	352.60	20.00
O_2	2.05	49.20	17958.00	16240.90	330.10	19.20
O_2 + CO_2	1.99	47.80	17447.00	16443.20	344.00	18.10

The rate of combustion face advance with such structural differences as roses will be 1.42 – 1.80 m/day. It depends on the mining-geological conditions, parameters and method of air injection, the number of reversing operations per day, the uniformity of the active zones displacement along the gasification channel length.

In the coal gasification complex located in the chamber opposite the gasifier, in addition to the installation of controlled pipelines supply, there is equipment for preparation and air injection in a well. Placing such equipment in mine conditions requires considerable expenses for installation and demolition works, in addition, as the parameters of the mine gasifier increase, the dimensions of the complex increase, which affects the growth of metal content.

Another technological solution for coal gasification is the use of flexible controlled pipelines equipped with injected blast activator. The application of this technical solution provides an effective activation of the gasification process along the gasification channel length, the proportioning of the blasting current to the combustion face mirror in each active zone of the gasifier.

This contributes to reducing the injected blast and coal losses, equal formation of the gasification channel and the blasting current reverse. The developed and patented technological scheme of a gasifier with drill injected blast activators for direct and separate influence on the oxidation and reduction zones in the gasification channel is depicted in Figure 3.

The underground gasifier preparation is carried out from mining's *9*, *11* in mining conditions. The horizontal exploitation wells *4*, *5* on the coal seam *1* with bankette formation (the gasification channel) *2* between them with airway *9* are carried out from the haulage gate *11*. In the air injection holes and gas-conducting wells flexible pipeline connected with docking device with drill injected blast activators *8* in a bankette *9* is installed. After this, the airway bankette separates from it with the heat-resistant phosphogypsum barrier *10*. After formation ignition, the bankette passes into the gasification channel. The formation ignition is carried out as in the above-described method (Fig. 2).

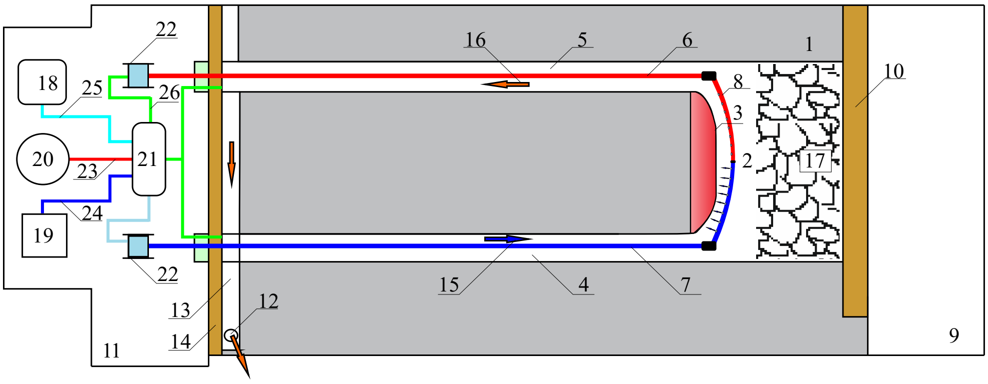

Figure 3. Technological scheme of a gasifier with a drill injected blast activators: 1 – coal seam; 2 – gasification channel of the gasifier; 3 – combustion face; 4 – air injection hole; 5 – gas-conducting well; 6, 7 – flexible pipeline with blast activators; 8 – drill injected blast activators; 9 – airway; 10 – heat-resistant phosphogypsum barrier; 11 – haulage gate; 12 – vertical gas-conducting well (connection with the surface cleaning complex and gasification products processing); 13 – gas-conducting bankette; 14 – heat-resistant phosphogypsum barrier; 15 – the direction of air blast supply; 16 – direction of gasification products venting; 17 – gasification affected area; 18 – compressor for air blast supply; 19 – oxygen capacity; 20 – steam generator; 21 – fault plane dispenser of blast components; 22 – a device for moving a flexible pipeline with roses; 23 – steam line; 24 – oxygen line; 25 – air line; 26 – blast pipeline

After ignition oxygen is supplied through the flexible pipeline to the gasification channel through the drill injected blast activators on the combustion face mirror of the oxidation zone. The process management is done taking into account the geological characteristics of the formation and the parameters of air injection into underground gasifier. Control over qualitative and quantitative parameters of the gasification product is carried out by gas analyzers, chromatographs and heat-sensing devices, gasometers.

The drill activator is moved behind the combustion face with the help of flexible pipelines. The gasification products from the gasification channel along the gas-conducting wells are directed under pressure to the gas-conducting bankette *13*, separated from the haulage gate by heat-resistant phosphogypsum barrier *14*. Later, the gas-condensate gasification product is directed to gasification products purifying and processing surface complex through a vertical gas-conducting well *12*.

Mass balance, technological parameters of a gasifier equipped with drill activators for c_5 coal seam gasification in mine conditions of Stashkova PJSC "DTEK Pavlohradvuhiillia" are given in Table 3.

Table 3. Technological indices of c_5 coal seam gasification using blast activators

Type of injected blast	The number of gasified coal				Duration of pillar gasification, days	Output of combustible gases (H_2, CH_4, CO) during gasifier operation, m^3
	t/hour	t/day	t/year	t/during exploitation period		
Air	2.12	50.97	18606.00	16373.30	321.00	9.50
Steam	2.30	55.30	20183.00	16603.10	310.30	20.40
O_2 + steam	2.05	49.30	18011.00	16930.30	343.10	22.20
O_2 + CO_2 + steam	2.04	49.10	17914.00	17018.30	346.80	21.80
O_2	2.10	50.50	18414.00	16388.50	324.90	20.10
O_2 + CO_2	2.08	48.60	17721.00	15948.90	338.50	19.50

Range expansion of the injected blast components application with chemical feed (oxygen, steam) directly to the combustion face mirror allows providing the required amount of heat for a short time, generated during exothermic reactions. In this case, through the activator, additional dynamic pressure is built on the burning coal area along the whole combustion face length. Thermal energy indicators of the oxidative zone provide balanced endothermic reactions behavior in the conditions of impulse superheated steam supply on the combustion face.

A comparative analysis of two technological schemes with roses and injected blast activator on the gasifiers energy indicators enables us to substantiate the feasibility of each scheme implementation. The main factors influencing the technical level of the scheme are the overall dimensions of the main air injection appliance. The characteristics of energy indicators change at coal gasification in two technological schemes with roses and injected blast activator are shown in Figure 4.

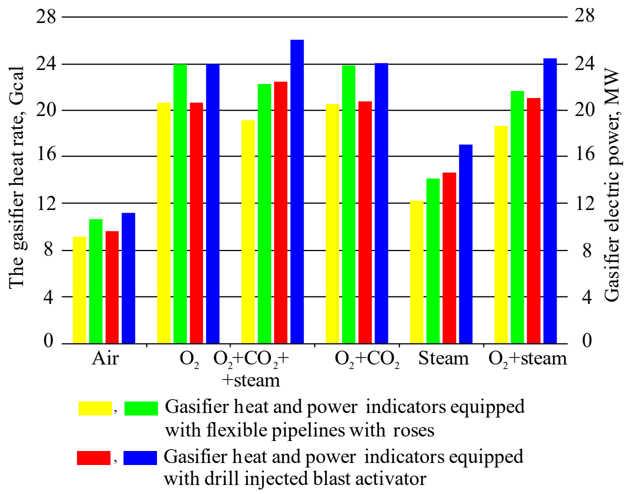

Figure 4. Energy indicators of the mine gasifiers work in various injected blast components supplying methods to the combustion face "mirror"

One of the main indicators of effective work is to ensure the quick adequate gasification operation during reverse work. Taking into account the previously established dependences of the underground gasification operation into cyclic reversing (Saik, Falshtynskyi, Dychkovskyi, & Lozynskyi, 2015) and the obtained results on the physic-chemical reactions in the combustion face, the authors of the work fixed the time of adequate gasification operation. The time changes of gasification operation, equipped with flexible pipes with roses and drill activators during reverse works are shown in Figure 5.

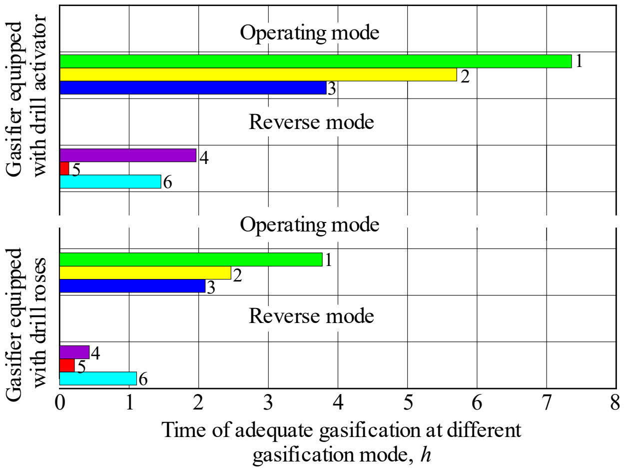

Figure 5. The diagram of fixed time of adequate gasification operation equipped with flexible pipes with drill activator and roses: 1 – ignition; 2 – formation of gasification channel active zones; 3 – achieving sufficient balance between oxidation and reduction zones of the gasification channel; 4 – gasifier blowing-out; 5 – ignition of the reduction zone and changeover into the oxidation; 6 – achieving sufficient balance between oxidation and reduction zones of the gasification channel (gasification process)

Reduction of the gasification operation time, equipped with the activator, is determined by the continuity, directionality and selectivity of the drill activators influence on the gasifier active zones. This allows combining the processes of formation ignition and gasification channel active zones balance. At the reverse, the combustion processes of the reduction zone are carried out simultaneously with the aim of changeover it into the oxidation one. At the same time there is a process of thermochemical operations effective balancing along the gasification channel length.

The bar chart of fuel gases output and diagram of combustion face advance at c_5 coal seam gasification, depending on the injected blast composition and appliance for its injection, are presented in Figure 6.

Analyzing the presented characteristics of two gasification technological schemes of low- thick coal seams gasification in mine conditions, one can state the advantages of introducing gasification constructions with drill activators. The disadvantages of such scheme are installed limit of the extraction gasifier pillar and gasification channel length, which is associated with the loads, which the equipment withstands when advancing the combustion face while coal gasification.

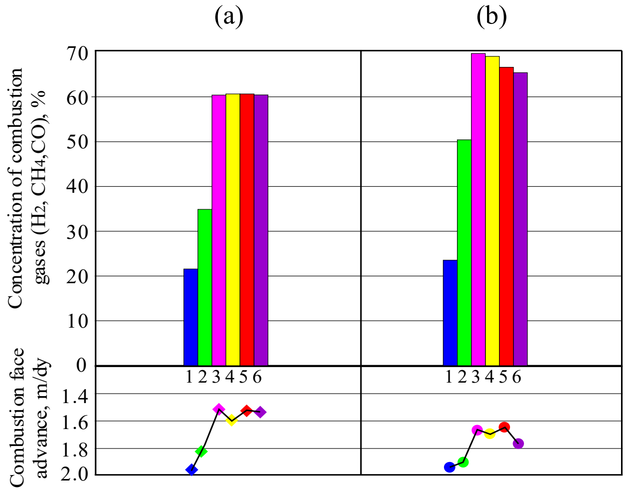

Figure 6. Bar chart of fuel gases output and diagram of combustion face advance, depending on the injected blast composition: (a) flexible pipeline with roses; (b) drill activators; 1 – air; 2 – steam; 3 – O_2 + steam; 4 – O_2 + steam + CO_2; 5 – O_2; 6 – O_2 + CO_2 and equipment for its injection

In further researches the authors plan to substantiate the gasification pillar size, based on the loadsthat flexible pipelines can withstand. This will allow us to establish the best possible technical support facilities for coal gasification.

4. CONCLUSIONS

The proposed technology is effective in working out profitable and non-commercial coal reserves in mine conditions, ensures the gasification process controllability, directionality and selectivity due to the direct active air components injection to the combustion face of the gasification zones. It allows to receive technical or energy gasification product of high quality with the further chemicals synthesis, to provide a high rate of process balance, to improve the ignition processes, to reduce the gasification channel active zones formation time and reverse, to reduce the exhaust gas and coal injected blast loss, to expand BUCG technology field of application.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education and Science of Ukraine, grants No.0116U008041 and No.0117U001127.

REFERENCES

Blinderman, M.S., Saulov, D.N., & Klimenko, A.Y. (2008). Forward and Reverse Combustion Linking in Underground Coal Gasification. *Energy*, *33*(3), 446-454. https://doi.org/10.1016/j.energy.2007.10.004

Blinderman, M.S. (2017). Application of the Exergy UCG Technology in International UCG Projects. *IOP Conference Series: Earth and Environmental Science*, (76), 012009. https://doi.org/10.1088/1755-1315/76/1/012009

Bondarenko, V.I., Griadushchiy, Y.B., Dychkovskiy, R.O., Korz, P.P., & Koval, O.I. (2007). Advanced Experience and Direction of Mining of Thin Coal Seams in Ukraine. *Technical, Technological and Economical Aspects of Thin-Seams Coal Mining, International Mining Forum, 2007*, 2-7. https://doi.org/10.1201/noe0415436700.ch1

Bondarenko, V., Svietkina, O., & Sai, K. (2017). Study of the Formation Mechanism of Gas Hydrates of Methane in the Presence of Surface-Active Substances. *Eastern-European Journal of Enterprise Technologies*, *5*(6(89)), 48-55. https://doi.org/10.15587/1729-4061.2017.112313

Borshchevska, Y. (2015). Path to Sustainability. Troubled Gradualism of the Unfinished Coal Mining Reform in Ukraine. *Journal of Security and Sustainability Issues*, *4*(4), 323-343. https://doi.org/10.9770/jssi.2015.4.4(2)

Dubiński, J., & Turek, M. (2016). Mining Problems of Underground Coal Gasification – Reflections Based on Experience Gained in Experiment Conducted in Katowicki Holding Węglowy S.A. Wieczorek Coal Mine. *Mining Science*, (23), 7-20.

Dychkovskyi, R.O., Lozynskyi, V.H., Saik, P.B., Petlovanyi, M.V., Malanchuk, Ye.Z., & Malanchuk, Z.R. (2018). Modeling of the Disjunctive Geological Fault Influence on the Exploitation Wells Stability during Underground Coal Gasification. *Archives of Civil and Mechanical Engineering*, *18*(4). https://doi.org/10.1016/j.acme.2018.01.012

Falshtynskyy, V., Dychkovskyy, R., Lozynskyy, V., & Saik, P. (2012). New Method for Justification the Technological Parameters of Coal Gasification in the Test Setting. *Geomechanical Processes during Underground Mining*, 201-208. https://doi.org/10.1201/b13157-35

Falshtyns'kyy, V., Dychkovs'kyy, R., Lozyns'kyy, V., & Saik, P. (2013). Justification of the Gasification Channel Length in Underground Gas Generator. *Annual Scientific-Technical Collection – Mining of Mineral Deposits*, 125-132. https://doi.org/10.1201/b16354-23

Falshtynskyi, V.S., Dychkovskyi, R.O., Saik, P.B., Lozynskyi, V.H., & Cabana, E.C. (2017). Formation of Thermal Fields by the Energy-Chemical Complex of Coal Gasification. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 36-42.

Gladii, A. (2017). Armed Conflict in Donbas in the Years 2014/2015 – Internal Split or the Ukrainian-Russian War? Eventual Models for the Further Development of the Conflict. *Przeglad Strategiczny*, (10), 95-118.

Jiang, L., Chen, Z., & Ali, S.M.F. (2017). Modelling of Reverse Combustion Linking in Underground Coal Gasification. *Fuel*, (207), 302-311. https://doi.org/10.1016/j.fuel.2017.06.097

Kharlamova, G., Chernyak, O., & Nate, S. (2016). Renewable Energy and Security for Ukraine: Challenge or Smart Way? *Journal of International Studies*, *9*(1), 88-115. https://doi.org/10.14254/2071-8330.2016/9-1/7

Langan, W.T., & & Friggens, G.R. (1991). Overview of Advanced Coal Combustion and Conversion Clean Coal Technology Demonstration Program. *American Society of Mechanical Engineers*, 1-7.

Li, Y., Liang, X., & Liang, J. (2007). An Overview of the Chinese UCG Program. *Data Science Journal*, (6), S460-S466. https://doi.org/10.2481/dsj.6.s460

Lozynskyi, V.H., Dychkovskyi, R.O., Falshtynskyi, V.S., & Saik, P.B. (2015). Revisiting Possibility to Cross Disjunctive Geological Faults by Underground Gasifier. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 22-28.

Lozynskyi, V., Saik, P., Petlovanyi, M., Sai, K., & Malanchyk, Ye. (2018). Analytical Research of the Stress-Deformed State in the Rock Massif Around Faulting. *International Journal of Engineering Research in Africa*, (35), 77-88. https://doi.org/10.4028/www.scientific.net/JERA.35.77

Mocek, P., Pieszczek, M., Świądrowski, J., Kapusta, K., Wiatowski, M., & Stańczyk, K. (2016). Pilot-Scale Underground Coal Gasification (UCG) Experiment in an Operating Mine "Wieczorek" in Poland. *Energy*, (111), 313-321. https://doi.org/10.1016/j.energy.2016.05.087

Nieć, M., Sermet, E., Chećko, J., & Górecki, J. (2017). Evaluation of Coal Resources for Underground Gasification in Poland. Selection of Possible UCG Sites. *Fuel*, (208), 193-202. https://doi.org/10.1016/j.fuel.2017.06.087

Petenko, I.V., & Maidukova, S.S. (2014). Problemy rentabelnosti vuhilnoi produkcii. *Coal of Ukraine*, 18-27.

Saik, P., Falshtynskyi, V., Dychkovskyi, R., & Lozynskyi, V. (2015). Revisiting the Preservation of Uniformity Advance of Combustible Face. *Mining of Mineral Deposits*, *9*(4), 487-492. https://doi.org/10.15407/mining09.04.487

Saik, P.B., Dychkovskyi, R.O., Lozynskyi, V.H., Malanchuk, Z.R., & Malanchuk, Ye.Z. (2016). Revisiting the Underground Gasification of Coal Reserves from Contiguous Seams. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 60-66.

Snihur, V., Malashkevych, D., & Vvedenska, T. (2016). Tendencies of Coal Industry Development in Ukraine. *Mining of Mineral Deposits*, *10*(2), 1-8. https://doi.org/10.15407/mining10.02.001

Vivcharenko, O. (2012). Development of Coal Industry of Ukraine in the Context of Contemporary Challenges. *Geomechanical Processes during Underground Mining*, 1-5. https://doi.org/10.1201/b13157-2

Wang, G.X., Wang, Z.T., Feng, B., Rudolph, V., & Jiao, J.L. (2009). Semi-Industrial Tests on Enhanced Underground Coal Gasification at Zhong-Liang-Shan Coal Mine. *Asia-Pacific Journal of Chemical Engineering*, *4*(5), 771-779. https://doi.org/10.1002/apj.337

Wiatowski, M., Kapusta, K., Świądrowski, J., Cybulski, K., Ludwik-Pardała, M., Grabowski, J., & Stańczyk, K. (2015). Technological Aspects of Underground Coal Gasification in the Experimental "Barbara" Mine. *Fuel*, (159), 454-462. https://doi.org/10.1016/j.fuel.2015.07.001

Xin, L., Wang, Z., Wang, G., Nie, W., Zhou, G., Cheng, W., & Xie, J. (2017). Technological Aspects for Underground Coal Gasification in Steeply Inclined Thin Coal Seams at Zhongliangshan Coal Mine in China. *Fuel*, (191), 486-494. https://doi.org/10.1016/j.fuel.2016.11.102

Yang, L. (2003). Clean Coal Technology – Study on the Pilot Project Experiment of Underground Coal Gasification. *Energy*, *28*(14), 1445-1460. https://doi.org/10.1016/s0360-5442(03)00125-7

ІННОВАЦІЙНІ АСПЕКТИ В ТЕХНОЛОГІЇ ШАХТНОЇ ГАЗИФІКАЦІЇ ВУГІЛЬНИХ ПЛАСТІВ

В. Фальштинський, П. Саїк, В. Лозинський, Р. Дичковський, М. Петльований

Мета. Розробка інноваційних підходів до удосконалення технологічних та технічних рішень при шахтній газифікації вугілля.

Методика. Проведення аналізу вітчизняного та світового досвіду з розробки вугільних запасів технологією підземної газифікації, аналітичні дослідження з визначення параметрів матеріально-теплового балансу процесу газифікації, напружено-деформованого стану гірського масиву навколо шахтних газогенераторів та визначення техніко-економічних показників їх роботи.

Результати. Аналітичними розрахунками напружено-деформованого стану порід для умов шахт Західного Донбасу встановлено, що максимальна довжина стовпа газифікації повинна складати не більше 580 м. Запропоновані інноваційні технологічні схеми підготовки ділянки пласта шахтних газогенераторів у двох конструкціях:

з перфорованими насадками та з перфорованим активатором дуття. Визначені енергетичні показники роботи шахтних газогенераторів, термін виходу у режим газифікації при здійснені реверсних робіт та виходу паливних газів при різному посуванні вогневого вибою та складу дуття. Рекомендовано за численними перевагами впровадження конструкцій шахтних газогенераторів з перфорованим активатором.

Наукова новизна. Встановлено залежність зміни довжини стовпа шахтного газогенератора від техніко-економічних показників роботи станції газифікації; залежності виходу шахтного газогенератора у режим газифікації та виходу генераторних газів залежно від складу дуття та швидкості посування вогневого вибою.

Практична значимість. Обґрунтовано раціональні параметри підготовки вугільного пласта при шахтній газифікації, а також енергетичні та технологічні показники цього процесу. Розроблено нові технологічні схеми відпрацювання запасів вугілля шахтною газифікацією, що дозволить додатково залучити забалансові та залишені у межах шахтних полів запаси вугілля та подовжити термін існування гірничих підприємств.

Ключові слова: *підземна газифікація, вогневий вибій, газогенератор, генераторний газ, матеріально-тепловий баланс*

ИННОВАЦИОННЫЕ АСПЕКТЫ В ТЕХНОЛОГИИ ШАХТНОЙ ГАЗИФИКАЦИИ УГОЛЬНЫХ ПЛАСТОВ

В. Фальштынский, П. Саик, В. Лозинский, Р. Дычковский, М. Петлёваный

Цель. Разработка инновационных подходов к совершенствованию технологических и технических решений при шахтной газификации угля.

Методика. Проведение анализа отечественного и мирового опыта по разработке угольных запасов технологией подземной газификации, аналитические исследования по определению параметров материально-теплового баланса процесса газификации, напряженно-деформированного состояния горного массива вокруг шахтных газогенераторов и определение технико-экономических показателей их работы.

Результаты. Аналитическими расчетами напряженно-деформированного состояния пород для условий шахт Западного Донбасса установлено, что максимальная длина столба газификации должна составлять не более 580 м. Предложенные инновационные технологические схемы подготовки участка пласта шахтных газогенераторов в двух конструкциях: с перфорированными насадками и с перфорированным активатором дутья. Определены энергетические показатели работы шахтных газогенераторов, срок выхода в режим газификации при осуществлении реверсных работ и выхода топливных газов при различном подвигании огневого забоя и состава дутья. Рекомендовано по многочисленным преимуществам внедрение конструкций шахтных газогенераторов с перфорированным активатором.

Научная новизна. Установлена зависимость изменения длины столба шахтного газогенератора от технико-экономических показателей работы станции газификации; зависимости выхода шахтного газогенератора в режим газификации и выхода генераторных газов в зависимости от состава дутья и скорости подвигания огневого забоя.

Практическая значимость. Обоснованы рациональные параметры подготовки угольного пласта при шахтной газификации, а также энергетические и технологические показатели данного процесса. Разработаны новые технологические схемы отработки запасов угля шахтной газификацией, что позволит дополнительно вовлечь забалансовые и оставленные в пределах шахтных полей запасы угля и продлить срок существования горных предприятий.

Ключевые слова: *подземная газификация, огневой забой, газогенератор, генераторный газ, материально-тепловой баланс*

ARTICLE INFO

Received: 26 October 2017
Accepted: 31 March 2018
Available online: 6 April 2018

ABOUT AUTHORS

Volodymyr Falshtynskyi, Candidate of Technical Sciences, Associate Professor of the Underground Mining Department, Dnipro University of Technology, 19 Yavornytskoho Ave., 49005, Dnipro, Ukraine. E-mail: fvs@yahoo.com

Pavlo Saik, Candidate of Technical Sciences, Associate Professor of the Underground Mining Department, Dnipro University of Technology, 19 Yavornytskoho Ave., 49005, Dnipro, Ukraine. E-mail: saik.nmu@gmail.com

Vasyl Lozynskyi, Candidate of Technical Sciences, Associate Professor of the Underground Mining Department, Dnipro University of Technology, 19 Yavornytskoho Ave., 49005, Dnipro, Ukraine. E-mail: lvg.nmu@gmail.com

Roman Dychkovskyi, Doctor of Technical Sciences, Professor of the Underground Mining Department, Dnipro University of Technology, 19 Yavornytskoho Ave., 49005, Dnipro, Ukraine. E-mail: dichre@yahoo.com

Mykhailo Petlovanyi, Candidate of Technical Sciences, Associate Professor of the Underground Mining Department, Dnipro University of Technology, 19 Yavornytskoho Ave., 49005, Dnipro, Ukraine. E-mail: petlyovany@ukr.net