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Technical and technological support of the technology of activating the process of gasification of thin coal seams

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Abstract:

According to the tests results of the technology of reverse jet flow, to balance the geometric and physical parameters of the active zones of the reaction channel of the underground gas generator during the gasification of low-power coal seams. The parameters of activation of the oxidizing and reducing zones of the fire blowout were established, taking into account the outgassing of the coal seam in space and time, the impact of mining and geological parameters as well as geotechnical and thermochemical processes, securing the even advance of the fire blowout along the length of the reaction channel of the underground gas generator. It was established that the intensification of the gasification process of thin and ultrafine coal seams increases the quantitative and qualitative parameters of exothermic and endothermic reactions, which have an impact on increasing the efficiency of the underground georeactor and determines the quality parameters of the gasification product.

Keywords: experimental bench plant, model of the gasification process, underground gas generator, reaction channel, fire break, low-power coal seams, reverse mode

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1. Introduction

The technical and technological support of the process of underground gasification of coal includes a set of measures and equipment necessary for the effective implementation of this process. Underground coal gasification is the process of converting coal seams into high-calorific gas, which can be used for the production of electricity, heat, synthesis of various chemical products and fuel gases [1-3].

The main components of the technical and technological support of the process of underground gasification of coal are the following:

- Mine infrastructure. This includes construction and maintenance of mines for opening the coal seams. Mines that involve the synthesis technology within one facility must be equipped with special systems of ventilation, safety and monitoring of working conditions [1, 4];
- Gasification plant. This is the main equipment used to convert coal into gas. This installation includes a gasification channel, where chemical reactions take place, and systems for supplying gaseous mixtures and removing the gasification products [2, 5, 6];
- Gas purification and treatment systems. The resulting gas contains a certain amount of impurities that must be removed before its use. Gas cleaning and processing systems include filters, condensing units and other equipment for cleaning and preparing gas to be a commercial product [5, 7];
- System of transportation and accumulation. Cyclic or continuous flow systems are used to transport the prepared technical gas. This may include special piping systems, tanks and gas storage tanks [5, 8];
- Energy supply and automation systems. Appropriate power supply, automation and control systems are used to secure proper management of the gasification process and to monitor operating parameters [5, 9];
- Safety and environmental systems. Ensuring the safety of workers and the environment is a major aspect of underground gasification. This system includes a ventilation network, safety sensors, gas control systems and other measures [10].

Due to the complexity and potential risks of underground coal gasification, effective technical and technological support is important to ensure the successful implementation of this process and minimize negative impacts on the environment. During the gasification of thin coal seams, significant heat losses are observed in the rock of the roof and floor, which significantly affects the output of the gas generator during the production mode of the gasification process [10, 11]. In the production mode, there is an increase in the speed of the fire in the oxidizing zone and an increase in the length of the reaction channel, which leads to an imbalance between exothermic processes in the oxidizing zone and endothermic processes in the reducing zone, negatively affecting the performance of the underground coal gas generator [12]. Reverse operation aims at activating the thermochemical processes of coal gasification, relevant at the first stages of putting the underground gas generator into operation, as well as at the end of the work [13]. When operation of the underground gas generator is stopped, destabilization of the gasification process of the coal seam leads to a decrease in leak tightness coefficient of the georeactor, which significantly affects the parameters of the coal seam gasification due to the loss of coal and generator gases as well as blowing [4].

Establishing the rational technological parameters for reversing the active zones of the reaction channel of the underground gas generator is especially relevant in the regimes of ignition of a thin seam, the transition to the gasification regime, and in the process of extinguishing in thermochemical processing and mining of a coal seam.

2. Materials and Methods

Research work on implementation of reverse technology in the gasification of low-power coal seams were developed at the "Pidzemgaz" plants in gasification of thin hard coal seams in the conditions of Donbas region, but the designs of underground gas generators and technological innovations of that time did not allow testing and implementation of reverse technologies.

Gained Ukrainian and foreign experience in designing and operation of industrial and experimental underground gas generators allowed scientists of the Dnipro Polytechnic National Technical University to develop new designs of underground gas generators and technologies for activating the gasification process of low-power coal seams with adaptation to complex mining and geological conditions [2].

New technological solutions increasing the reliability and efficiency of the gasification process of thin coal seams were developed by modelling the rock-coal seam, the coal seam and the construction of the underground gas generator on experimental installations according to the criteria of similarity [14].

According to the information of operating underground gas generators, bench and laboratory tests and analyses of parameters of the technology of reversing the active zones of the reaction channel of an underground gas generator, it was established that the main reasons for the unstable operation of underground low-power gas generators during gasification of coal seams є [15] are the following:

- heat loss during the active heat exchange of the fiery blowout of the coal seam with the rocks in it;
- non-uniformity of the advance of the fire exit from the reaction channel of the gas generator due to the higher advance of the oxidizing zone;
- losses of dust mixtures, generator gas and coal when the gas generator space increases and the appropriate tightness of the underground gas generator changes.

In today realities, the most available methods of testing the parameters of the technology of intensification of the process of gasification of low-power coal by reversing the active zones of the reaction channel of the underground gas generator of formations, taking into account the impact of mining and geological conditions, are the analysis of experience in the gasification of thin coal seams, bench tests and methods of mathematical and computer modelling with application of software packages such as MTBalance SPGU, "Devices Systems", Monitor QB. and "GeoDenamics Lite" [12].

Modelling and testing the coal gasification processes in underground boreholes was carried out on the ESU, designed and patented at the Dniprovska Polytechnic National Technical University [16]. The coal seam, structures of the underground gas generator, rock stratum and coal gasification processes were created according to the criteria of the similarity and suitability of the coal seam to the LNG. Assembly, preparation and testing the SPGV in ESU were performed on industrial sites with the financial and technical support of DTEK "Pavlogradvugilya", the company "Donetskstal" and the Ministry of Science and Education of Ukraine (Fig. 1).

One of the points of testing was establishing the rational parameters of the t reverse operation for activation of fire breakout zones in the conditions of an increase in the gassed space, changes in the tightness and length of the reaction channel of the underground gas generator, taking into account space and time.

Fig. 1. Assembly, preparation and testing the SPGV in ESU: 1 – transitional cooling box; 2 – condensate tank; 3 – generator gas cooling tank; 4 – a container for collecting condensate; 5 – gas outlet pipeline; 6 – IRVIS sensor; 7 – configurator for cleaning generator gas from hydrogen sulphide (H2S); 8 – chimney; 9 – transition pipe; 10 – vertical gas outlet pipe; 11 – section No. 1, testing and measuring complex (thermocouples): display of temperature sensors (thermocouples), TERA "Devices System" software based on the Firebird 2.1 database; 12 – reserve compressor; 13 – main compressor; 14 – steam generator; 15 – section No. 2, system for controlling quantitative parameters of generator gas blowing and pressure: IRVIS - K300, gas analysers Garboards 3200L and BX-170. The change in displacement of the roof rocks, as the gasification area of the gas generator increases, was provided by the database of reference sensors and the Monitor QB program; 16 – formation of a solid coal together with the installation of reference sensors

3. Results

3.1. Formation of the gas generator system and its start-up

Ignition of a coal seam, fire treatment and creation of a reaction channel, during the experiment, was secured by reversing the stream flows with the optimization of the material-heat balance of the thermochemical process during the transition from burning to gasification of coal in the seam with formation of adaptive parameters of the oxidation and reduction zone and stabilization of the auto thermality of the LNG process during balancing exothermic and endothermic reactions.

Control of the gasification process of the thin coal seam model took place from the intake control unit and the blow reverser. Part of the air blast was fed through the blast well, and the active part of the blast mixture (oxygen, steam) was fed through a flexible pipeline directly to the fire outlet in the oxidation zone of the reaction channel, where exothermic processes generating heat, ensures activation of endothermic processes in the reduction zone, forming the balance of physical rates and kinetics of thermochemical reactions.

The coal seam was ignited through the ignition hole of the test stand (Fig. 2, a) d = 100 mm with the help of red-hot pieces of coal and the blowing of air enriched with oxygen (O_2 = 28÷40%, with a consumption of Q = 1.8÷3 m^3/min). The ignition temperature of the G-grade coal seam and pressure were recorded using a pyrometer, pressure sensors, and thermocouples and were in the range of T = 405÷538°C, at a pressure of p = 0.14÷0.2 MPa. The direction of the blow-through of the channel between the blowhole and the gas-discharge well coincided with the direction of the blow and was in the temperature range of T = 584÷705°C with a pressure of p = 0.25÷0.36 MPa, while the speed of the blow-through of the channel was V_k = 0.7÷0 .96 m/h. According to the testing method, the initial stage of the blow-through of the reaction channel of the gas generator was carried out in the blowing mode, shift to the combined mode "compressor - flue draft" made it possible to reduce the pressure p = 0.14÷0.3 MPa and increase the speed of the blow-through V_k = 1÷1.3 m/h. Formation of active zones and thermal intensification of the reaction channel of the gas generator model was provided by the reverse flow of the blast from the blast and gas discharge wells to the fire hole in the temperature range T = 695÷1004°C with a pressure of p = 0.2÷0.28 MPa, which made it possible to form an oxidizing, transitional and the recovery zones of the gas generator. Length of the oxidation zone was 27÷33% the reaction channel, the transition zone was 0.4÷0.7%, the reduction zone was the length of the remaining reaction channel.

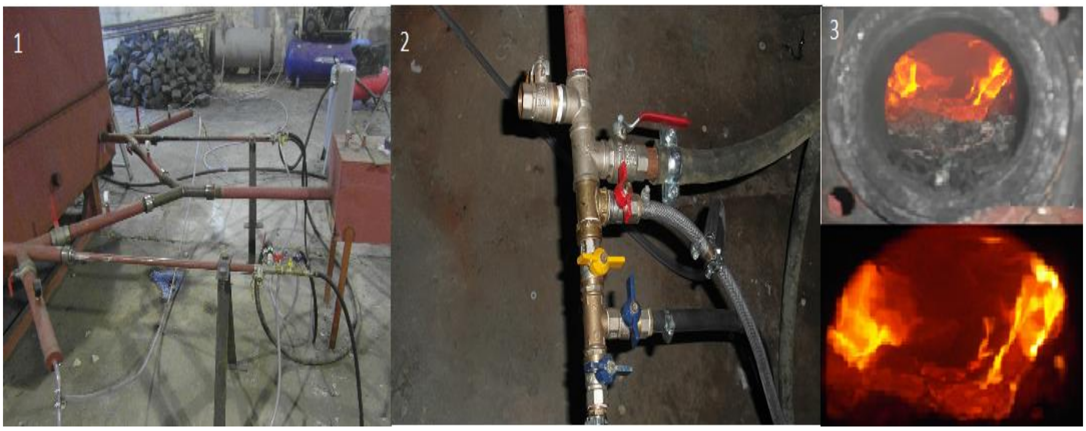

Fig. 2. The coal seam ignition process and the thermal treatment of the reaction channel of the underground gas generator model: 1 – connection of the unit for the integration of the supply and discharge of blast mixtures and generator gas with the gas generator stand: 2 – the control system for blast supply modes and reverse operations; 3 – visualization of the activation of oxidation and reduction zones when applying reverse streams

Reversing the dust mixtures and control of supply and pressure regimes during ignition and formation of the reaction channel allowed after 3 hours bring the gas generator into stable gasification mode. After 3 hours 40 minutes of the test, at 0.2 m from the point of the blast supply in the oxidation zone of the reaction channel, the temperature in the range T=590÷685°C was recorded by a pyrometer. At 0.76 m from the point of blowing, the temperature reached T=884÷1007°C, the oxygen content did not exceed 1.5%, and the carbon dioxide content reached 12.6%.

Temperature of the roof rocks after 5 hours and 35 minutes of heating, above the fire hole at 0.1 m from the point of the blast was 412÷470°C, at 0.62 m – 566÷734°C, at 0.87 cm – 664÷750°C, at 1.18 m – 450÷529°C. The generator gas output was 2.1÷2.4 m^3/min, with an average water content of 182.5 g/cm^3 and with a lower combustion temperature in the range of 2.5-7.2 MJ/m^3.

Increase of the degassed space of the gas generator by the dimensions $S_{v.p.} = 0.12 \div 3.86$ m^2 and the change in tightness of the gas generator were observed, depending on the degree of coal gasification in the seam, as well as the increase in the length of the oxidation zone and the reaction channel, associated with the displacement of the roof rock layers, the growth of vertical and horizontal fracturing, and the difference in the speed of advance of the active zones of the gas generator. At the tenth hour of the test, destabilization of the gasification processes was recorded: changing in the temperature regime and pressure along the reaction channel, a change in the quantitative and qualitative composition of the generator gas, which is associated with increase of ballast gases and a decrease in calorific value.

Application of the reverse technology of the active zones of the reaction channel in the underground gas generator, variations in the modes of supply by blowing pressure made it possible to align the line of the fire gap, to restore the appropriate length of the reaction channel, and also to stabilize the quality indicators of the generator gas. Thanks to the reverse technology, the coal seam gasification process was maintained for 5 hours and 30 min at the damping stage, according to the method of the experiment and the stable transition from gasification to the mode of damping the work.

Parameters of the fuel components of the generator gas during the bench test on the gasification of a low-power coal seam are shown in Fig. 3.

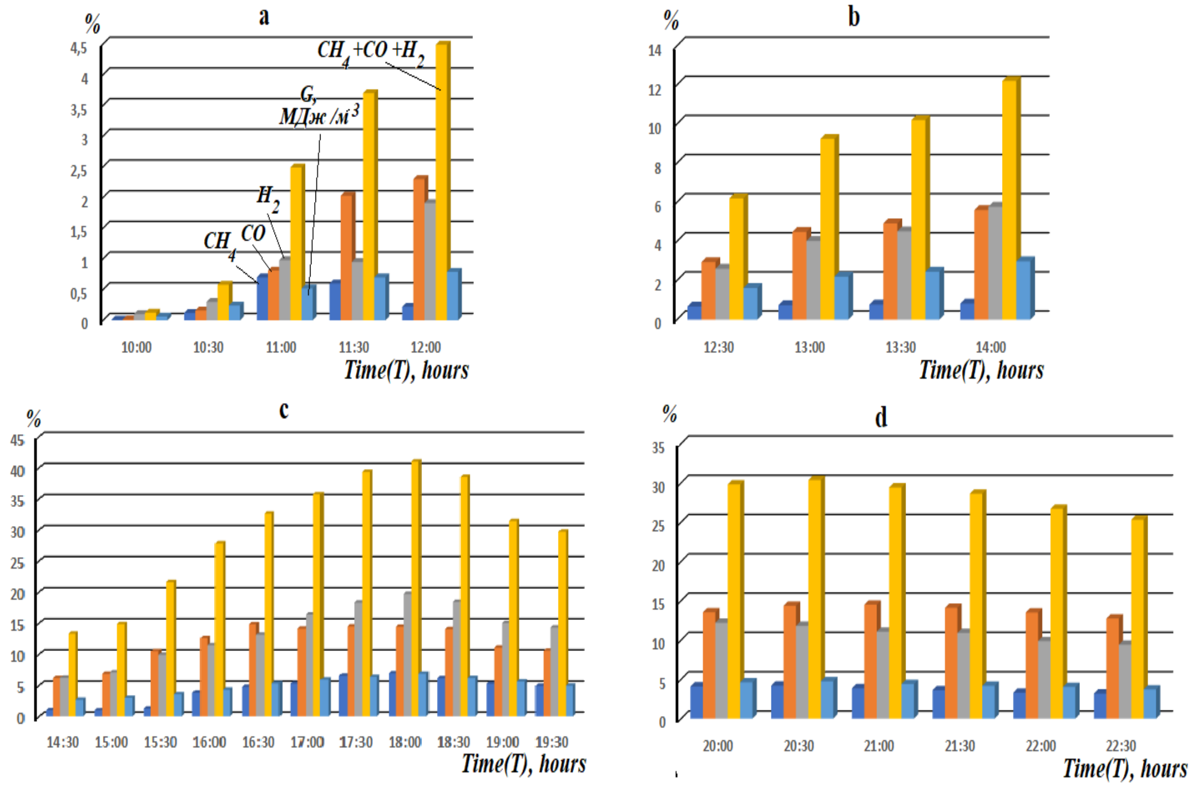

Fig. 3. Parameters of the fuel components of the generator gas during the bench test on the gasification of a low-power coal seam: a – mode of ignition, burn-through and formation of the reaction channel; b - mode of reverse works for the formation of active zones of the reaction channel of the underground gas generator; c – mode of productive, balanced gasification of a thin coal seam; d – mode of reverse operations maintaining the proper parameters of gasification in a view of increasing the gasified space and the loss of required tightness by the gas generator during stopping the work on gasification of a thin coal seam

When using reverse operations on the side of the recovery zone of the reaction channel of the gas generator, the following is provided: no blast mode, removal of generator gas through the blast well in a exhaust gases pipe, supply of oxygen-enriched blast ($O_2 = 35 \div 62\%$) through a flexible control pipeline directly to the fire outlet, as well as steam-air blast along the gas borehole. During the bench test, after 58 min changes in temperature and productive parameters along the length of the zone were recorded, an increase in the heat capacity C, kJ/(kg K) and a decrease in the thermal conductivity λ, W/(m K) of the gas condensate of oxidation processes containing rocks. The pressure during reverse operations was in the range of 0.45-0.6 MPa at the beginning of operations, while the oxidation processes was stabilized the pressure was 0.18-0.22 MPa.

Fig. 4 presents the results from testing the parameters of reverse operation during the underground gasification of a low-power coal seam in the real conditions, taking into account mining and geological, technological and geo-mechanical parameters as well as the thermochemical process of gassing the coal seam of the SPGV site.

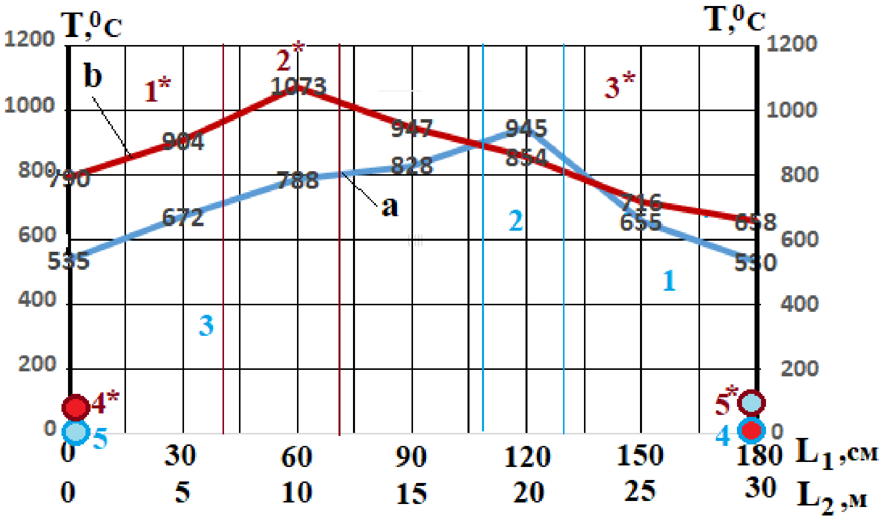

Fig. 4. Temperature and technological parameters of reverse operations during the bench test on underground gasification of a low-power coal seam: 1 – temperature distribution before the reverse (initial stage of process damping), 2 – temperature distribution after the reverse (the process of a stable gasification regime), 4 - oxidizing zone, 5 - transition zone, 6 - reducing zone, 7 - jet borehole (stable gasification process), 8 - gas removal borehole (stable gasification process)

3.2. Analyses of the technological parameters of reverse operations during underground gasification of a low-power coal seam.

Calculation of displacement of the oxidation and reduction zone of the reaction channel of the underground gas generator is based on the results of mine tests, bench tests and data on the material balance of the underground coal gasification process.

According to analysis, the quantitative parameters of coal gasification in the oxidation zone of the reaction channel of the underground gas generator are determined using the following formula:

$$A_{\text{окz.}} = \frac{Q_{okz}}{n},\ \text{t/h} \tag{1}$$

where:

Q_{okz} – gas production by the oxidation zone, m^3/h,

n – the volume of generator gas per one kg of coal, 2 m^3/kg,

in the regeneration zone:

$$A_{v.z} = \frac{Q_{v.z.}}{n},\ \text{t/h} \tag{2}$$

where:

$Q_{g/g}$ – generator gas output from the gas generator, m^3/h;

$Q_{v.z}$ - production of gas by reduction, $Q_{v.z} = Q_{g/h} - Q_{ok.z}$, t/h.

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After determining the parameters of coal outgassing in the active zones of the reaction channel, the speed of advance of the generator gas escape was justified:

$G_{\text{v.d.}}$ – the amount of coal gasified per day, $Q_{\text{ok.z}} + Q_{\text{v.z}} \cdot T_g$, t/day; $G_{\text{v.1p.m}}$ - amount of coal in 1m.p. fire impact, $G_{\text{v.1p.m.}} = l_{\text{r.k.}} \cdot 1 \cdot m \cdot \gamma$, t/1p.m:

– advance of fire escape of the underground gas generator

$$V_{\text{v.v}} = \frac{G_{\text{v.d.}}}{G_{\text{v.1p.m.}}}, \text{ m/day} \tag{3}$$

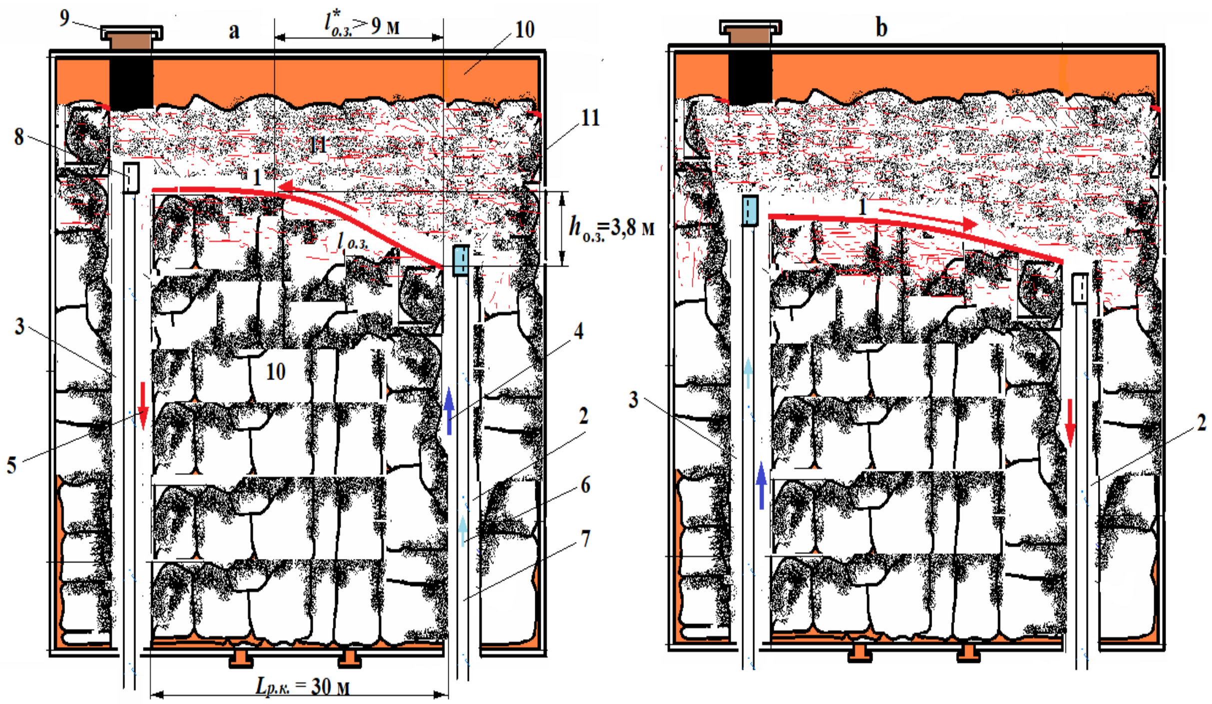
– advance of the fire gap of the recovery zone of the reaction channel

$$A_{\text{v.z.day}} = A_{\text{v.z.day}} \cdot T_G, \text{ t/day}; \; V_{\text{v.z.day}} = \frac{A_{\text{v.z.day}}}{G_{\text{v.1p.m.}}}, \text{ m/day} \tag{4}$$

– difference between the advance of gaps in the oxidizing zone and in the reducing reaction channel of the underground gas generator

$$V_{ok.z} = V_{\text{v.v.}} - V_{\text{v.z.}}, \text{ m/day} \tag{5}$$

According to the calculation (Fig. 5), the increase in the length of the reaction channel of the underground gas generator is determined, taking into account the difference in the advance of the active zones.



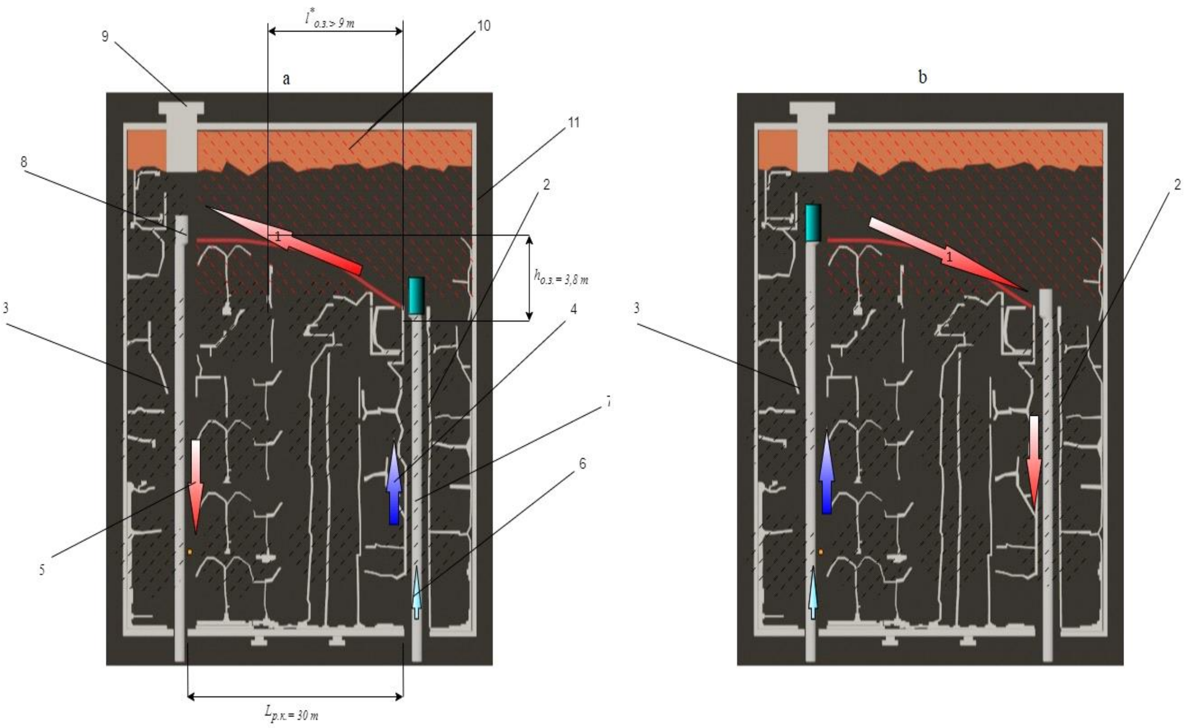


Fig. 5. Scheme for calculating the onset of reverse work according to the main technological parameter - the length of the oxidation zone of the reaction channel: a – conditions for the onset of reverse work; 1 – reaction channel of the gas generator, 2 – blow borehole, 3 – gas discharge borehole, 4 – air blowing, 5 – generator of gases, 6 – oxygen-enriched blowing, 7 – controlled flexible pipeline, 8 – heat-resistant perforated nozzle, 9 – coal bed ignition nozzle , 10 – thermal insulation, 11 – degassed space of the gas generator; b –reverse operation to activate the zones of the gas generator reaction channel

Increase in the length of $\mathbf{L_{r.k.}}$ and oxidation zone $\mathbf{l_{o.z,}}$ the reduction or absence of the transition zone and the reduction of the reduction zone of the reaction channel due to the increase in the speed of the flame discharge of the oxidation zone, which affects the balance of the gasification process is the reason for starting the reverse operation:

$$l_{\text{o.z.}} = \sqrt{{l^*_{\text{o.z.}}}^2 + {h_{o.z}}^2}\text{, м} \tag{6}$$

$$l_{v.z.} = L_{r.k.} - l_{\text{o.z}}\text{, м} \tag{7}$$

where:

$l^*_{\text{o.z.}}$ – length of the oxidation zone of the reaction channel in the underground gas generator 9 м,

$l_{v.z..}$ – regeneration zone, m.

An increase in the length of the oxidation zone by 30% or more leads to an imbalance in the generation and transfer of thermal energy for thermochemical reactions in the reduction zone of the gas generator. Under these conditions, it is assumed that reverse operations ensure the linearity of the fire gap and activate the gasification processes, creating conditions for the balance of the active zones of the reaction channel of the gas generator. The results of bench and analytical tests on implementation of reverse operations during the gasification of low-power hard coal seam C6, grade DH, Solinovsk coal basin, Pokrovsky district, with a capacity of m=0.7-0.75 m, are presented in Fig. 6.

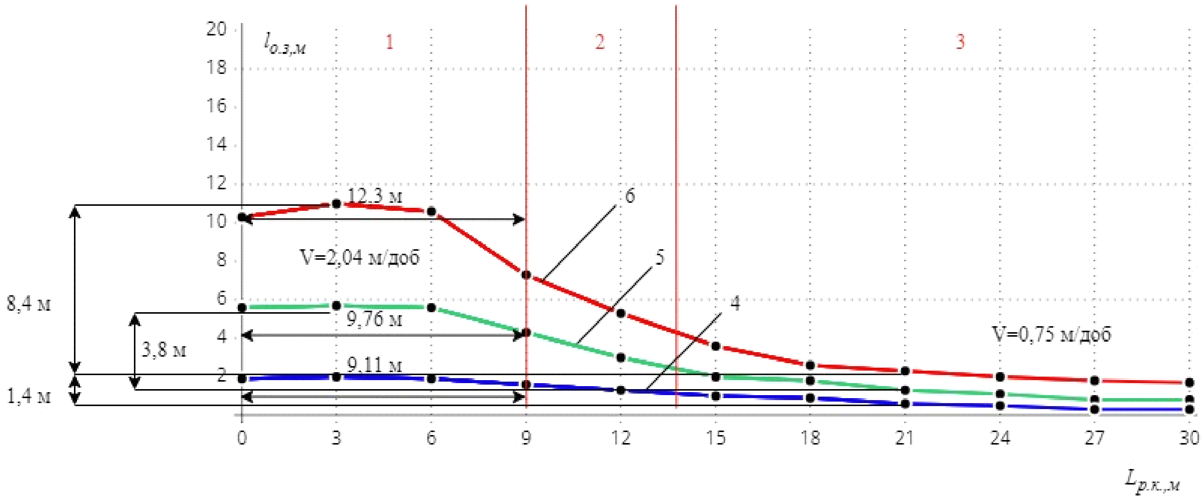


Fig. 6. Impact of the parameters of the reaction channel zones movement in the underground gas generator on the conditions of the onset of reverse operation, taking into account geological conditions, technical indicators and geo-mechanical parameters: 1 - oxidizing zone, 2 - transition zone, 3 - reducing zone, 4 - 1 day, 5 - 2 days , 6 - 3 days; 1.4, 3.8, 8.4 m – increase of the parameters of advance of length of the oxidizing zone after fire breaks out, relative to the length of the reducing zone; 9.11, 10.16, 12.3 m - increase in the length of the oxidation zone, according to the difference in the speed of the active zones of the gas generator

Balancing the thermochemical processes, geometrical and temperature parameters as well as directionality of gasification of the coal seam during reverse operations, ensured the formation of active zones of the reaction channel of the gas generator in 1.2 - 1.35 hours. According to the results of the temperature range, the energy balance of the reaction channel and the composition of the generator gas, during the bench tests and analyses, it should be stated that the recovery and stability of the gasification process has been achieved in the short time from starting the reverse work [15].

3.3. Chemistry of the reverse operations during underground gasification of a thin coal seam

Among the gasification processes, there are autothermal ones, in which the heat required for the endothermic gasification process is obtained from burning part of the injected fuel, and autothermal ones, in which the required heat is supplied from the outside using a solid or gaseous medium. In practice, these processes are used in combination - multi-stage gasification. The coal gasification process is associated with the reactions given in Table 1.

Table 1. The main chemical reactions of the gasification process

Reaction	ΔH, kJ/mole
$C + O_2 = CO_2$	– 393,7
$C + 0{,}5O_2 = CO$	– 109,4
$C + CO_2 = 2\ CO$	+ 172,5
$C + H_2O = CO + H_2$	+ 131,4
$C + 2H_2O = CO_2 + 2H_2$	– 41,1
$C + 2H_2 = CH_4$	– 74,8
$CO + 3H_2 = CH_4 + H_2O$	– 206,2
$2CO + 2H_2 = CH_4 + CO_2$	– 123,8

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It should be noted that the thermodynamic basis of the coal gasification process has been investigated, but their kinematics has not been sufficiently explained.

Depending on a way using the generator gas, such conditions are applied in which a gas-condensate mixture of the required composition is obtained.

Realities of the fuel and energy complex of Ukraine have a significant need for hydrogen, synthesis gas, reducing gases for the gasification of solid fuels and, first of all, from balance reserves, cut and crushed coal, thin and ultra-thin coal seams. Generator gas is processed as a chemical raw material, therefore the content of carbon dioxide (CO_2) and nitrogen (N_2) in its composition should be minimal, therefore the advantage in the thermochemical gasification of solid fuel under pressure when using oxygen (steam-oxygen blowing mixtures).

For various chemical reactions, the mixtures of CO with H_2 of different ratios are used. For example, for the synthesis of methanol or aliphatic hydrocarbons, a gas with a ratio of $CO:H_2=1:2$ is used, and when aldehydes are obtained by the hydroformylation reaction (oxosynthesis), a synthesis gas with a ratio of $CO:H_2=1:1$, which reacts with olefins, is used. For the synthesis of methane the ratio $CO:H_2$ should be 3:1.

Changing the composition of the generator gas during gasification, regarding the CO and H_2, is possible by processing it using the following conversion process:

- catalytic conversion of carbon monoxide (to increase the hydrogen content);
- catalytic conversion of methane (to increase the synthesis gas content);
- scrubbing from carbon dioxide (to increase the oxidant content).

Depending on the conditions of the gasification process, it is possible to change the composition of the obtained gas, for example, to increasing the content of carbon monoxide in the gas is possible by increasing the reaction temperature. The power of the gas generator is determined by many parameters (pressure, temperature, composition of dust mixtures, contact time). This process is carried out in three main ways: in a stationary mode, in a fluidized bed and in a flow of pulverized fuel. Also the method of well underground gasification (SGU) on moving nozzles and an activator [15] has been developed as well as gasification in the environment of molten coolants (ash, salt, metals). Plasma gasification of pulverized fuel, during which the oxidizer is heated to high temperatures, enables intensification of the coal gasification process.

It is possible to increase the efficiency of the reaction in the process due to the reverse chemical transport [16]. The reverse process was modelled on the basis of a chemical system consisting of a cylindrical tube placed in a furnace with a constant temperature (Fig. 7).

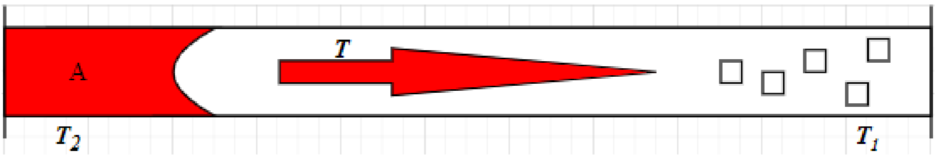

Fig. 7. Chemical transport in a cylindrical tube. Transport from the zone with temperature T2 to the zone with temperature T1

The basic principles of chemical transport can be demonstrated when transport reactions take place in a cylindrical tube with a different temperature between its ends, using the following equation:

$$\text{A (solid)} + \text{B (gas)} = \text{AB (gas)},$$

$$n_{AB} = (Dqt/sRT)(P_{AB(2)} - P_{ABm}),$$

where n_{AB} is the number of moles of substance AB that diffused, D is the diffusion coefficient, q is the cross section of the tube, s is the length of the diffusion path, t is the process duration, R is the gas constant, T is the absolute temperature along the diffusion path, $P_{AB(i)}$ is proportional to the pressure of component *AB* at the point with temperature T_1.

In the right-hand side of the expression for pAB, the first factor reflects the gas displacement and the apparatus constant, and the second factor reflects the heterogeneous reaction. In this case $\mathbf{T_2 > T_1}$.

If a solid substance A reacts with a gaseous substance B to form a gaseous compound AB, and if this reaction is reversed, then chemical transport can occur. If the observed reaction is endothermic, the solid substance A will decompose at higher temperatures T2 with the formation of a gaseous compound AB, while after the migration of AB to the point with temperature T1, the reverse reaction occurs and component A is deposited from the gas phase. In the case of exothermic reactions proceeding in the same temperature gradient, part of the substance is moved in the reverse direction $T_1 \rightarrow T_2$.

Diffusion in the gas phase is the stage that determines the rate of the total transport reaction. This means that the concentration gradient necessary for diffusion is determined by the presence of heterogeneous equilibrium at temperatures $\mathbf{T_2}$ **and** $\mathbf{T_1}$.

According to this equation, metals and silicates contained in the rock can be transported in significant quantities through the gas phase at 1200^0 C or at higher temperatures. Further, at lower temperatures, they are deposited in the form of well-formed crystals that serve as catalysts for the reversible process. Exothermic transport reactions have long been known, investigated in the research work of Van Arkel, as well as Van Arkel and de Boer [17]. These studies found wide, practical use in purification of metals.

Concentration gradient caused by the temperature dependence of the heterogeneous equilibrium is the driving force of the process. When selecting the transport reactions, the following factors are of significant importance:

- chemical transport is possible only when gaseous substances participate in the reactions (except for the transfer of solid matter). Only in this case, all components are mobile in the gas phase;
- the reaction must be reversed;
- the equilibrium position of transport reactions should not be sharply shifted either towards the starting substances or towards the gaseous product. Otherwise, the concentration gradient is negligible.

By substituting the real values into the diffusion equations ($q \approx 3$ cm^2, $s \approx 10$ cm), the transfer can be efficient if the factor $\Delta P_{AB}/\Sigma P$ P equals at most 10^{-4}. It follows that not one of the partial pressures that should be taken into account in the transport process cannot be less than the value given by this factor.

Under other constant conditions, the transfer efficiency will be small when the gradient (ΔP_{AB}) will be maximum. In this case, the free energy of the transfer reaction will be near zero. However, these conditions are not necessary.

When the transport reaction is not connected with the next reaction, the necessary concentration gradient in the gas phase is also decisive for the reactions to proceed under isothermal heating conditions (practically). The important terms are described in the following equations:

zone 1: A (solid) + B (gas) = AB (gas) (1)
zone 2: AB (gas) + C (solid) = AC (solid) + B (gas); (2)
totally: A (solid) + C (solid) = AC (solid). (3)

The above statements regarding the determination of the factor $\Delta P_{AB}/\Sigma P$ are also valid in the cases (1) and (2). During chemical transport, several heterogeneous equilibria can take place at the same time, therefore, when calculating the concentration gradient necessary for transport reactions, all these equilibria should be taken into account [7].

The main way to reverse the process is its conversion. In essence, the method is based on the reverse process of methane oxidation with steam, oxygen or carbon dioxide according to the following reaction:

$$CH_4 + H_2O \leftrightarrow CO + 3H_2$$
$$CH_4 + 0.5O_2 \leftrightarrow CO + 2H_2$$
$$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2$$

It is possible to carry out "compatible" processes of steam-oxygen or steam-carbon conversion of natural gas (methane). Based on this, the reverse process can also be used for the processing of gaseous fuels produced during the direct LNG process.

The introduction of catalysts increases the rate of CH_4 conversion and lowers the temperature. The process takes place in the presence of a catalyst, which is formed during chemical transport at temperatures of 750÷780°C under conditions of reaching equilibrium. Despite the fact that the composition of methane in the mixture increases with increasing pressure, the conversion must take place under pressure in order to increase the reaction rate and reduce the volume of equipment and gas pipelines. In addition, all the processes of synthesis of organic products from CO and H_2 can take place at elevated pressures, therefore, when the conversion is carried out under pressure, the energy consumption for gas compression is reduced, which leads to energy savings.

It should be stated that the reversal is necessary, from the point of view of chemical thermodynamics, when the described conditions and processes are met.

4. Conclusions

According to the results of the evaluation of the received actual data of the modelling the technical conditions.

Implementation of the technology of reverse operations during the gasification of low-power coal seams at various stages of coal gasification at the LNG plant allowed for:

- reducing the time for ignition, burnout and formation of the reaction channel of the underground gas generator;
- creating the reaction, transition and recovery zones in a short time in an active-stable mode of activation of the process of thermochemical processes of gassing the coal seam;
- ensuring the appropriate length of the active reaction zones of the fire breakout in a stable temperature regime of gasification, taking into account the geo-mechanical parameters of the rock mass containing the gas generator, with increased convection heat exchange in the rock mass.
- maintaining the activity and stability of the gasification process in real conditions and given parameters during the gas generator attenuating mode, with the increase of the gassed space, changes in the integrity of the rocks of the roof and the floor of the coal seam, and the loss of leak tightness by the underground gas generator.

As it results from testing, in the cited research publications, the technological schemes, techniques and technology for reverse operations during borehole gasification of thin coal seams, characteristic for the coal deposits, have been presented.

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