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MINING AND TRIGENERATION OF GASES IN MINE TAKES AND MINES

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ВИДОБУТОК І ТРИГЕНЕРАЦІЯ ГАЗІВ НА ГІРНИЧИХ ВІДВОДАХ І ШАХТАХ

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ДОБЫЧА И ТРИГЕНЕРАЦИЯ ГАЗОВ НА ГОРНЫХ ОТВОДАХ И ШАХТАХ

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Annotation. Object of the research in this article is the processes of safety and energy efficiency control at hydrocarbon gas recovery and utilization during the coal extraction and development of mines. Subject of the research is criterion of safe, trouble-free and efficient operation of equipment and informational and resource-saving technology for the hydrocarbon gases recovery form the boreholes and mines and their further utilization. The structural and technological scheme of the mine trigeneration complex was developed on the basis of the studied technical solutions and results of the research works. For the complex design, the authors used an algorithm developed for uninterrupted control of boilers with using method of mathematical modeling of dynamics of its components and technical and economic aspects of the cogeneration of hydrocarbon gases. This algorithm provides issuing of preventive actions simultaneously in all channels of information input with a disturbing process of steam load changing.

Besides, parameters were determined and mnemonic schemes of explosion safety were developed for preparing gases for starting boilers and using the protection systems for preventing the spread of toxic gases and for uninterrupted operation. Additional input parameters are presented in the article: smoke gas consumption, methane concentration in the methane-air jet, and oxygen and methane concentration in the isolated mine workings, gas distribution point and boiler entrance. The health and safety criteria were established. They are calculated on the basis of new parameters that form control actions, which ensure explosion safety, trouble-free operation, and labor protection during the operation of the boiler unit. Further, on their basis, information tools were developed for controlling the stations of the boiler units, and safety criteria and conditions were established, which influenced on the reduction or increase in the frequency of the drive power used in the smoke exhaust system.

Keywords: mining safety, automated systems, visualization of three-dimensional models, control of geotechnical systems, boilers, coal gas, structural and technological scheme, trigeneration complex, hydrocarbon gases.

Introduction. To achieve energy independence, Ukraine masters the extraction and cogeneration of gas from coal deposits of coal mine methane and secondary types of hydrocarbon gases of various productions. In the works of NAS academicians N.S. Poliakova and A.F. Bulata, F.A. Abramova. Doctors of technical sciences: B.A. Griaduschii, E.L. Zviagilskii, K.K. Sofiiskii, B.V. Bokii, I.A. Efremov, V.G. Perepelitsa, L.E. Filimonov and other scientists have developed scientific and technical foundations for the safe joint production and transportation of coal and methane in amounts sufficient for the energy independence of Ukraine and have practically proven the energy efficiency of creating coal cogeneration complexes using the example of PJSC "Mine of A.F. Zasiadko". Construction of such complexes will ensure the reliability of electricity and heat supply to mines, as well as adjacent residential areas and enterprises and their survival during the restructuring of the coal industry. This direction of the development of mines is humane in relation to people associated with coal, proven reserves, which will be enough for Ukraine for 400 years. The effective SOU – 2004 for mine degassing normalizes the unacceptable concentration of methane in the degassing mixture of 3.5–25%. The disadvantage of this rationing method is that the methane concentration of 3.5–25% is typical for degassing systems in Ukraine and the mixture cannot be used as fuel by heat and power consumers, and must be flared, and is actually released into the atmosphere [1], which causes to low energy efficiency cogeneration stations not only in Ukraine but also in world practice.

Surveys and analysis of the operation of boilers at many CHP plants have shown that the supply of hydrocarbon gas and the air is usually controlled manually. At the same time, the air/gas ratio is not maintained at which high efficiency is ensured and at the same time in the flue gases there would be no toxic gases (nitrogen and carbon oxides), higher than the maximum permissible concentration. Managing the amount of underpressure in the furnace is also carried out manually, which does not exclude the possibility of filling the premises of CHP plants with poisonous gases above the MPC or extinguishing the flame on the burners and the explosion in the furnace of the boiler.

Accidents of the explosion of methane-air mixtures of the boiler units occur instantaneously, therefore, to prevent them, it is necessary to computerize the process and proactive emergency protection.

An aim of the work is to develop a basic structural and technological scheme and information of security and safety at the disposal of gas from coal deposits in mining allotments and mines.

Methods.

1. The method of calculating the parameters of the control actions of the relay regulator is reduced to the establishment of regularities that make it possible to determine the explosion-proof limits for the ratio of the concentration of oxygen and methane at the outlet of the gas mixing control point. Analytical studies and expert evaluation of the explosive diagrams of methane-air mixtures of Kauerd and Ayruni establish the regularities of its explosion-proof according to the ratio of oxygen and methane concentrations. Considered ranges of methane concentrations from 0 to 5%, from 5 to 20% and from 20 to 25%. On the basis of the established regularities, using the method of signature mathematics, equations are obtained for calculating the parameters of the control actions of the relay controller with negative hysteresis.

2. Methods of experimental research in industrial conditions of TPP of DniproAzot JSC on the establishment of regularities of gasification of rooms of TPPs with poisonous gases depending on pressure in the furnace of the boiler unit, extinction of the flame on the burners depending on vacuum in the furnace and formation of toxic nitrogen oxides and carbon monoxide in the furnace of the boiler depending on the oxygen concentration measured in the flue gas behind the

superheater is as follows:

- verification of measuring channels of O_2, *NO*, *CO* concentration, F_{st} steam consumption and vacuum in the furnace for compliance with the accuracy class of measuring transducers with the design of the verification protocol;
- measurement of O_2, *NO*, *CO* concentrations depending on steam consumption and establishment of regularities of *NO*, *CO* concentrations on O_2 concentration;
- measurement of concentrations of *NO*, *CO* in the CHP room depending on the pressure in the boiler furnace and determination of the extinction of the flame on the burners depending on the vacuum in the furnace and the establishment of regularities between them;
- according to the established laws, using the method of signature mathematics to solve boundary problems of information technologies, they obtain equations for calculating occupational safety criteria in CHP premises and criteria for preventing emergency stops of the boiler unit due to flame extinction on burners.

Results and its discussion. Structural and technological scheme of the mine trigeneration complex.

On the basis of research, technical solutions and R&D results, cited in [2], an algorithm developed in the trouble-free control of boilers, using mathematical simulating of the dynamics of its links [3] and the technical and economic aspects of the cogeneration of hydrocarbon gases complex [4], presented in Figure 1.

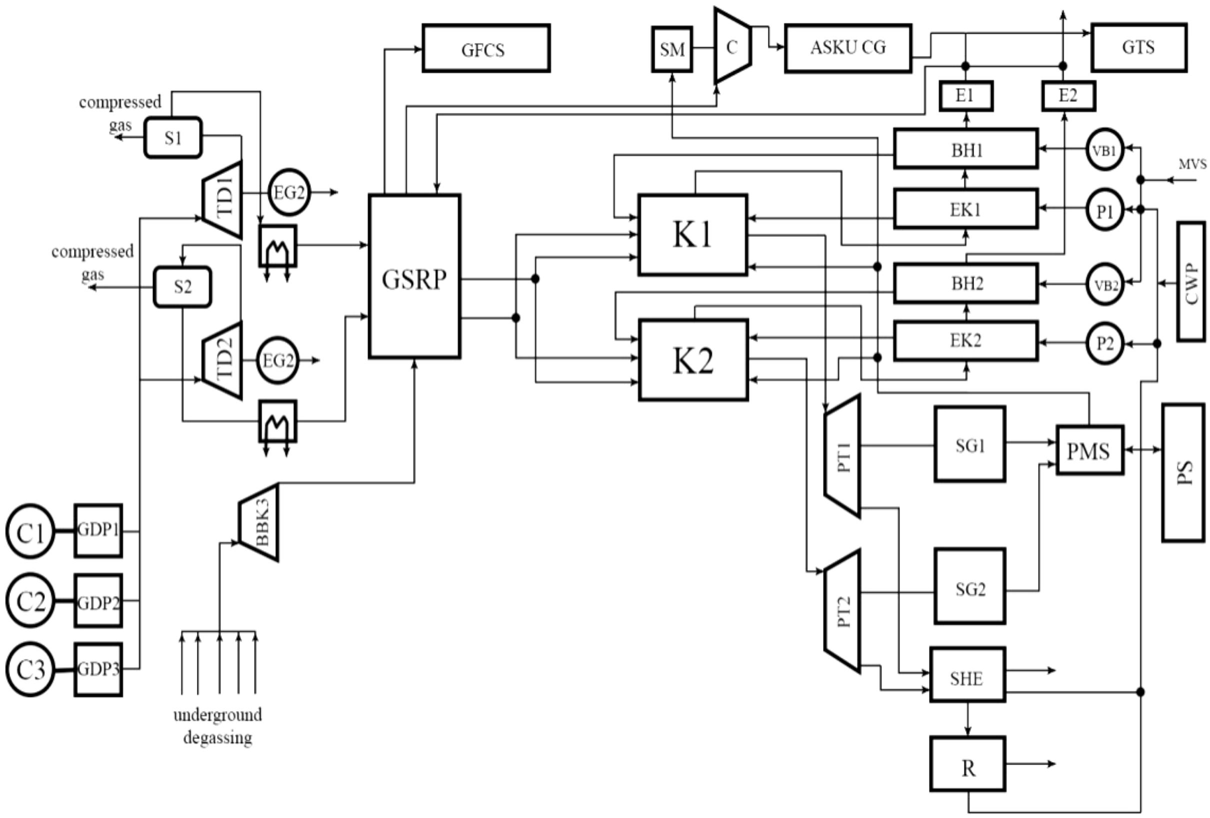

Figure 1 – Structural and technological scheme of the mine trigeneration complex: GDP – gas distribution plant, S – separator, GFCS – gas filling compressor station, SM – synchronous motor, E – exhauster, VB – ventilation blower, PS – power supply, PMS – power metering system, SHE – steam heat exchanger, P – pump, C – compressor

On an input of the multifuel boiler units *K*1, *K*2 the mine methane is supplied, extracted by underground vent wells with low concentration of methane from 10-40% retrieved by means of the vacuum and vortex BBK3 compressor, and the methane of high concentration, retrieved by superficial wells of mountain branches *C*1, *C*2, *C*3 after *TD*1, *TD*2 turboexpanders and the gas-mixing regulatory point GSRP. For utilization of the methane of ventilating streams of the MVS mine, with the percentage in the air up to 1% of CH_4, it needs to be warmed up by *BH*1 and *BH*2 air heaters due to the heat of the leaving combustion gases and it must be supplied instead air in the multifuel boiler units *K*1 and *K*2.

From exits of the boiler units, high-pressure vapours – $4 \cdot 10^6$ Pa supply on an input of *PT*1, *PT*2 steam turbines on the shaft of which the synchronous generators *SG*1, *SG*2 are set, generating the electric power W_e. Low-pressure vapour from the steam turbines' outputs moves in the heat exchanger where the heat energy W_t are generated for heating undermines buildings. The warm going out of the heat exchanger moves on the refrigerator (*R*). At the exit we have got the cold W_x, sending into underground mine workings. Steam condensate, after the heat exchanger and the refrigerator, returns to the boiler units together with purified water from the station of the chemical water purification (*CWP*) which is warmed up in *EK*1 and *EK*2 economizers by the heat of the leaving combustion gases. The coal gas with a high concentration of methane after turboexpanders is supplied in the separator which cleans it from liquefied propane-butane. After the separator, gas goes to the GSRP gas-mixing regulatory point for preparation to transfer to the gas transmission system (GTS) of Ukraine and increasing in pressure by means of the compressor *K*. On the compressor underpressure the automated system of commercial accounting of coal gas (ASKU CG) described in the work [3] is installed. The developed cold after the turboexpanders also goes into the mine to normalize of the air temperature.

Figure 2, except the existing normalized input parameters, presents the additional input parameters and the established criteria of safety and labour protection calculated on the basis of the new parameters, which form the operating influences, providing explosion safety, fail-safety and labour protection at exploiting of the boiler unit.

Ensuring of the explosion safety of the gas mixes supplied on the boiler unit's inputs. Gas pipelines of coal gas (Fig. 3).

The supply of coal gas from gas-mixing regulatory point (GSRP) to the boiler has to be developed by the pipeline of Du of 350 mm which is equipped with the disconnecting electrified latch of 3-GN-9 and also cut-off valve 4-GN-9, a radical latch 1-GN-9, and a sheet latch 2-GN-9.

The gas supply to each torch is carried out on the gas pipeline of Du 250, with the electrified latches 6-GN-9, 7-GN-9 established on it and the manual latches 8-GN-9, 9-G.

The purge of pipelines of coal gas has to be provided by compressed air. Gas pipelines of mine methane (Fig. 4).

The supply of mine methane from GSRP to the boiler has to be carried out on two gas pipelines.

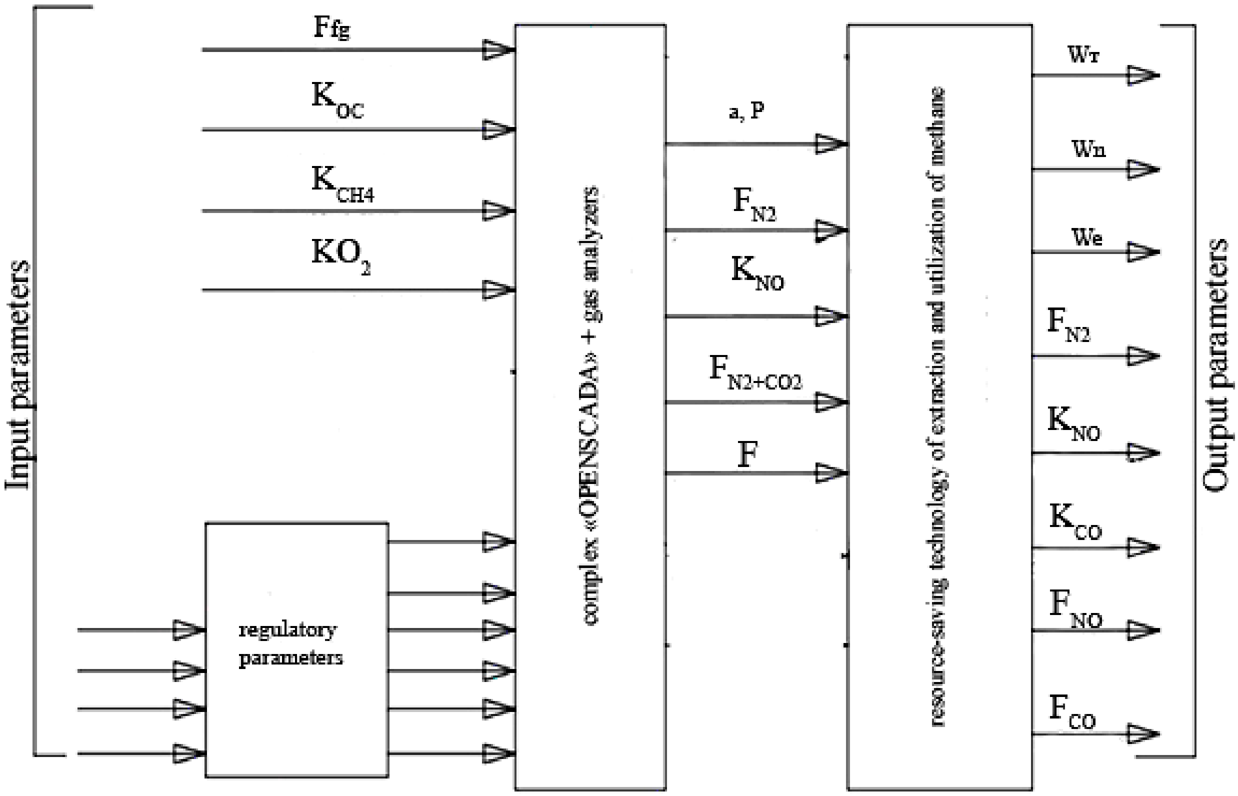

Figure 2 – List of input and output parameters of a steam-turbine trigeneration complex.

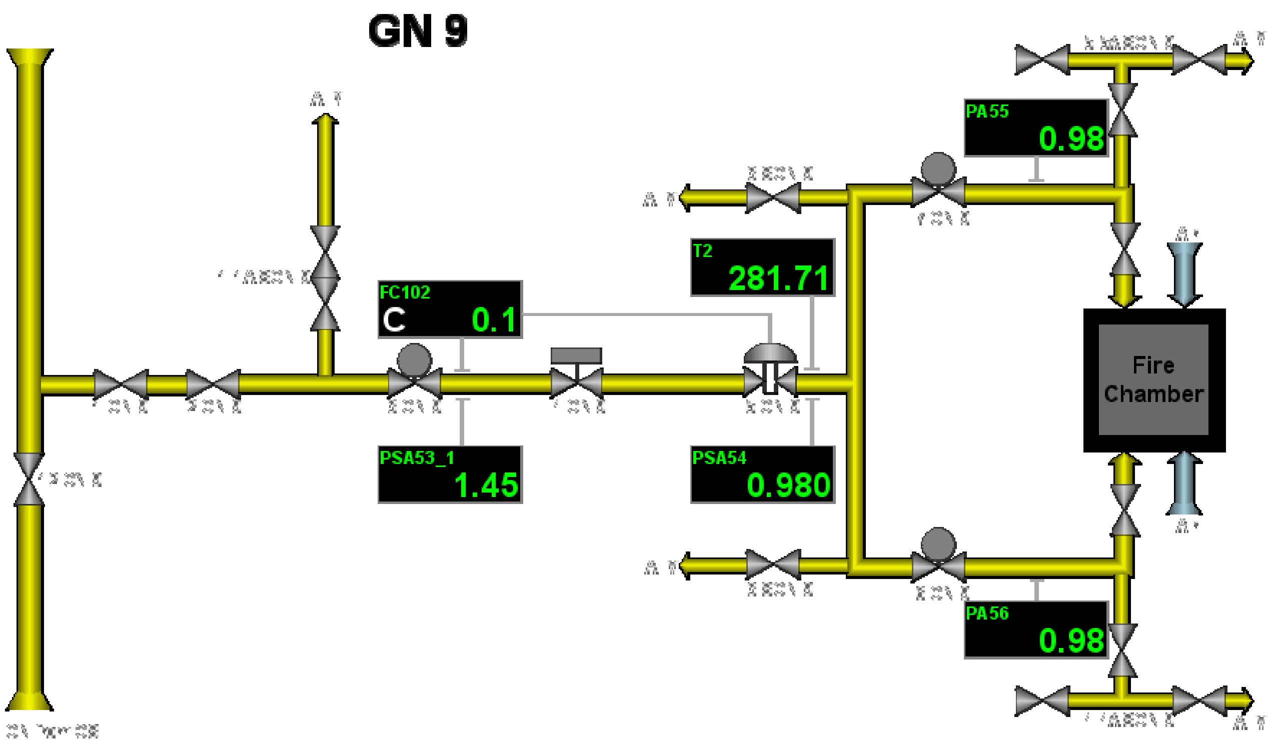

Figure 3 – Mnemonic scheme of the gas pipeline of coal gas of the automated system.

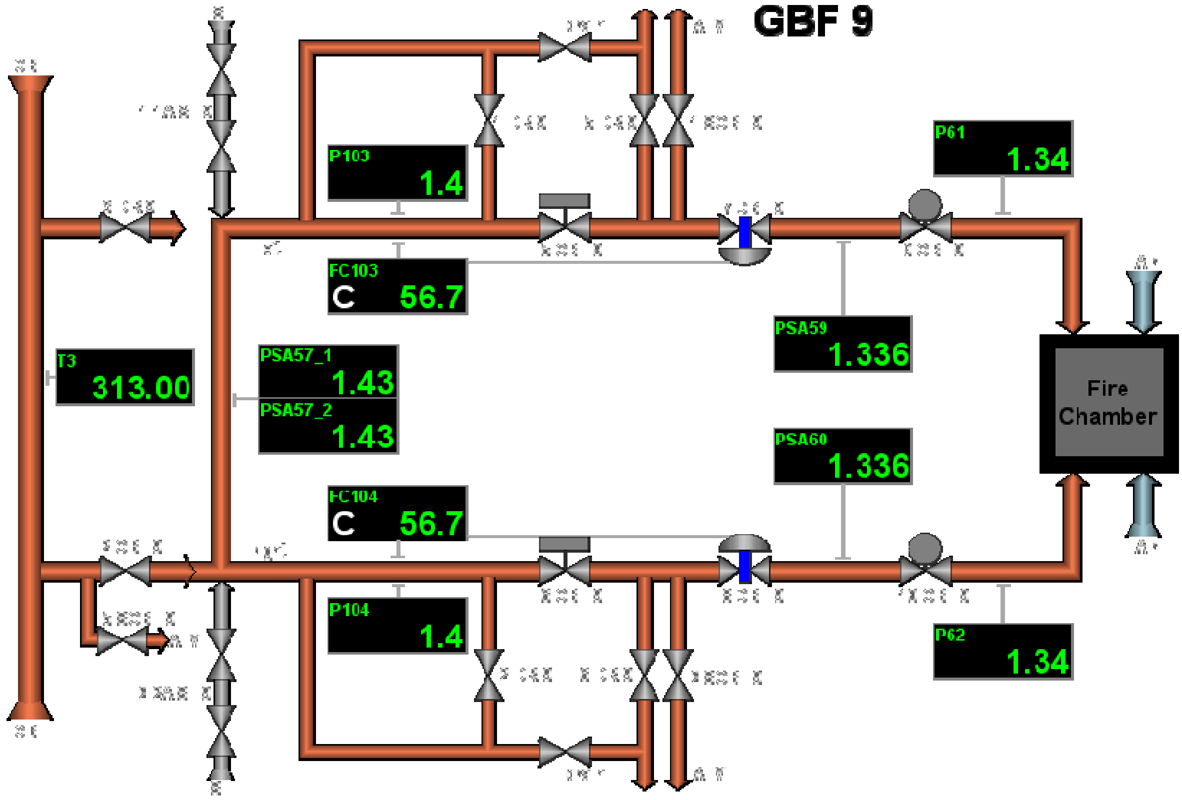

Figure 4 − Mnemonic scheme of the gas pipeline of mine methane of the automated system.

Before the measuring diaphragm (on the gas course) the sector latches 3-GD-8, 4-GD-8 have to be located and after the measuring diaphragm the cutting valves 5-GD-8, 6-GD-8, control valves 7-GD-8. 8-GD-8 and before torches the electrified latches 9-GD-8, 10-GD-8.

For steaming of gas pipelines of mine methane, before its reception and after shutdown, there a steam supply from the steam lines of $6{\cdot}10^5$ Pa is provided.

To remove of condensate from the gas pipelines, installation of steam traps is provided.

Start-up of coal mine methane into the gas pipelines of the boiler is allowed under conditions:

- ensuring its explosion safety with the GSRP regulator;
- a test of the operation of technological protections, interlocks, and alarms provided on the boiler.

According to the results of the explosion safety research given in [4], the following laws of the ratio of the concentration of oxygen to methane are established. The criterion for the explosion of hydrocarbon gases in the process of extracting them from insulated volumes of mines and preparation for utilization is determined according to the concentration of oxygen in the mixture of gases, which is inversely proportional to the concentration of methane in the range from 0 to 5% and is directly proportional to the concentration of methane in the range of 20 to 25%, and at a concentration of oxygen up to 7% the mixture is explosive at all concentrations of methane. On the basis of these regularities, the equation [2, 3, 4] is obtained for the solution of boundary value information space problems, by the method of signature mathematics for calculating control parameters of a relay controller.

Control Interface of the PC by means of the monitors *M*1 and *M*2 provides the boiler unit operator for all operational information necessary for safety at start-up, in the mode of normal operation, at planned and abnormal stops.

Ensuring explosion safety of mine methane is made by the GSRP-regulator by means of the below-mentioned criteria [5]:

Border from 0 to 5% of CH_4

$$K_{s1} = \frac{7 + \left|K_{CH_4} - 5\right| \cdot 2.6 - K_{O_2}}{7 + \left|K_{CH_4} - 5\right| \cdot 2.6} \cdot 20^{0.5\left[1 - Sign\left(7 + \left|K_{CH_4} - 5\right| \cdot 2.6 - K_{O_2}\right)\right]}. \quad (1)$$

Border from 5 to 20% of CH_4

$$K_{s2} = \frac{7 - K_{O_2}}{7} \cdot 20^{0.5\left[1 - Sign\left(7 - K_{O_2}\right)\right]}. \quad (2)$$

Border from 20 to 25% of CH_4

$$K_{s3} = \frac{20 + \left(K_{CH_4} - 20\right) \cdot 1.6 - K_{O_2}}{20 + \left(K_{CH_4} - 20\right) \cdot 1.6} \cdot 20^{0.5\left[1 - Sign\left(20 + \left(K_{CH_4} - 20\right) 1.6 - K_{O_2}\right)\right]}. \quad (3)$$

The main regulator holds for necessary pressure in the steam highway, providing and elimination of any redistribution of loadings between the working in parallel boiler units.

The thermal load regulator ensures functioning of the boiler on one of the following modes: on mine methane; on coal gas; and on mixes of coal gas and mine methane and also delivery at the same time on everything an entrance of regulators of the anticipatory signals proportional to the first derivative of indignation of an operating mode of the boiler unit of an expense couple [3].

The mine methane flow regulator is intended for maintenance of the set flow of mine methane during the work of the boiler on a mix of mine methane and coal gases. For ensuring a necessary range of regulation of thermal load of the boiler at the achievement of minimum flow of coal gas, the mine methane flow regulator is operated by a self-adjustment subsystem in the below-mentioned criteria [5, 6]:

- the criterion of energy efficiency:

$$K_{ee} = \frac{K_{O_2} - 2.3 - \left(F_{\Pi} - 100\right) \cdot 0.017}{2.33 - \left(F_{\Pi} - 100\right) \cdot 0.017} \cdot 20^{0.5}, \quad (4)$$

- the criterion of labour protection:

$$K_{lp} = \frac{3.0 - \left(F_{\Pi} - 100\right) \cdot 0.015 - K_{O_2}}{2.5 - \left(F_{\Pi} - 100\right) \cdot 0.015} \cdot 20^{0.5\left[1 - Sign\left(2.5 - \left(F_{\Pi} - 100\right) 0.015 - K_{O_2}\right)\right]}. \quad (5)$$

The depression regulator is intended for maintenance of the set depression in a fire chamber by the change of extent of opening of the guide vane of smoke exhausters on values of criteria of safety and labour protection of the boiler units in parameter underpressure.

$$K_{saf} = \frac{100 - P_T}{100} 20^{0.5[1 - Sign(100 - P_T)]},$$
$$K_{pr} = \frac{100 - |P_T|}{100} 20^{0.5[1 - Sign(100 - |P_T|)]}. \quad (6)$$

Conclusions.

1. Distinctive advantages of the developed control system are:

- existence of the GSRP gas-mixing regulatory point in which, by means of the established criterion of explosion safety, all extracted mine methane, including explosive concentration, is utilized;
- part of methane of the ventilating streams is burned in the fire chamber;
- ensures a steady trouble-free operation of the boiler unit, giving of anticipatory impacts at the same time on regulators of airflow, under pressure in the fire chamber, flow of gas and water supply;
- criteria of labour protection and energy efficiency allow to reduce of emerging in the fire chamber of poisonous gases (*NO* and *CO*) without reducing the boiler unit efficiency;
- forming of the operating influences, providing fail-safety at blackout of a torch and the requirement of labour protection for gas contamination of premises of the station with poisonous gases.
- the energy of cold for delivery to jobs in underground excavations is developed by turbodetandor, at pressure decline of coal gas, and refrigerators due to the transformation of not used thermal energy to the energy of cold.

2. The working projects for the creation of a commercial prototype control station for the gas trigeneration fail-safe operation in mine take can be developed.

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Анотація. Об'єктом дослідження в даній статті є процеси контролю безпеки та енергоефективності при видобутку і утилізації вуглеводневих газів при видобутку і розробці шахт. Предметом дослідження є критерій безпечної, безперебійної та ефективної роботи обладнання та інформаційно-ресурсозберігаюча технологія видобутку і утилізації вуглеводневих газів на свердловинах і шахтах. На основі досліджень технічних рішень і результатів науково-дослідних робіт розроблена структурно-технологічна схема комплексу тригенерації шахти. Для його розробки використовувався розроблений алгоритм безперебійного управління котлами з використанням методу математичного моделювання динаміки його ланок і техніко-економічних аспектів когенерації вуглеводневих газів. Даний алгоритм забезпечує видачу попереджувальних дій одночасно на всіх каналах введення інформації, зі збуреним процесом зміни навантаження пари.

Також, визначено параметри і розроблено мнемонічні схеми вибухобезпеки при підготовці газів до пуску котлоагрегатів, експлуатації захисту для запобігання поширенню отруйних газів і безперебійної роботи. . У статті також представлені додаткові вхідні параметри: витрата димових газів, концентрація метану з метано-повітряного струменю, концентрація кисню і метану з ізольованих гірничих виробок, газорозподільного пункту, входу до котла. Встановлені критерії безпеки та охорони праці. Вони розраховуються на основі нових параметрів, які формують управлінський вплив, що забезпечують вибухобезпечність, безвідмовну роботу і охорону праці при роботі котлоагрегату. На їх основі розроблено інформаційні засоби управління станціями котлоагрегатів і встановлено критерії та умови безпеки, які формують вплив на зниження або збільшення частоти потужності приводу системи випуску диму.

Ключові слова: гірнича безпеку, автоматизовані системи, візуалізація тривимірних моделей, управління геотехнічними системами, котли, вугільний газ, структурно-технлогічна схема, тригенераційний комплекс, вуглеводневі гази.

Аннотация. Объектом исследования в данной статье являются процессы контроля безопасности и энергоэффективности при добыче и утилизации углеводородных газов при добыче и разработке шахт. Предметом исследования является критерий безопасной, бесперебойной и эффективной работы оборудования и информационно-ресурсосберегающая технология добычи и утилизации углеводородных газов на скважинах и шахтах. На основе исследований технических решений и результатов научно-исследовательских работ разработана структурно-технологическая схема комплекса тригенерации шахты. В основе его разработки использовался разработанный алгоритм бесперебойного управления котлами с использованием метода математического моделирования динамики его звеньев и технико-экономических аспектов когенерации углеводородных газов. Данный алгоритм обеспечивает выдачу предупреждающих действий одновременно на всех каналах ввода информации, с возмущенным процессом изменения нагрузки пара.

Также, определены параметры и разработаны мнемонические схемы взрывобезопасности при подготовке газов к пуску котлоагрегатов, эксплуатации защиты для предотвращения распространения ядовитых газов и бесперебойной работы. В статье также представлены дополнительные входные параметры: расход дымовых газов, концентрация метана с метановоздушной струи, концентрация кислорода и метана с изолированных горных выработок, газораспределительного пункта, входа котел. Установлены критерии безопасности и охраны труда. Они рассчитываются на основе новых параметров, которые формируют управляющие воздействия, обеспечивающие взрывобезопасность, безотказную работу и охрану труда при работе котлоагрегата. На их основе разработаны информационные средства управления станциями котлоагрегатов и установлены критерии и условия безопасности, которые формируют влияние на снижение или увеличение частоты мощности привода системы выпуска дыма.

Ключевые слова: горная безопасность, автоматизированные системы, визуализация трехмерных моделей, управление геотехническими системами, котлы, угольный газ, структурно-технологическая схема, тригенерационный комплекс, углеводородные газы.

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