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JUSTIFICATION OF REGULATORY REQUIREMENTS FOR THE CONCENTRATION OF CARBON MONOXIDE IN THE ISOLATED SPACE OF THE ACCIDENT SITE BEFORE WRITING OFF A MINE FIRE

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Abstract. In 2023, three previously isolated exogenous fires happened in the mines of Ukraine in the conditions of the Pokrovske and Pershotravenske mines that had to be extinguished and then written off. These fires occurred as a result of explosions of methane-air mixture in the workings of excavation sites of the southern wall 11, block 10, and of the northern "bis" wall 9, block 10 in the Pokrovske mine and in the workings of the wall 586 in the Yuvileyna mine of the PJSC "DTEK Pavlogradvugillia".

The purpose of this work was to analyze the regulatory requirements for the safe value of carbon monoxide concentration in the isolated space of the accident site for writing off a fire.

Method. To achieve this purpose, it was necessary to perform an analysis of determining and to establish dynamics of changes in the background concentrations of carbon monoxide and hydrogen, as indicator gases, in the isolated space of the accident site of the southern wall 11, block 10 in the Pokrovske mine, and in the workings of wall 586 in the Yuvileyna mine.

Discussion. Since the background values of indicator gases in the places of the future fire are not always determined, it is probably necessary to somewhat increase the number of locations for assessing background values of CO and H_2 concentrations. Hence, there is a need to evaluate concentrations of tracer gases near explosion-proof bulkhead and at excavation sites, and also near other locations, for example, at the ends of degassing wells and in gas pipelines. Besides, it is necessary to specify more exactly the locations and order of mine measurements, as well as the method of calculating the safe parameters of indicator gases necessary for a possible write-off of a mine fire.

Practical significance. Based on the analysis of the conducted experiments and the results of fire extinguishing, recommendations were developed to clarify the regulatory documents by adding a clause to the new regulatory document in the following wording: "When extinguishing a fire by a combined method by way of flooding the accident (excavation) area and at a decrease in the temperature of water and air from the isolated site, the period for reducing values of concentration of indicator gases to safe limits can be shortened, for example, by 2–3 times, upon agreement with the SPMRS and availability of recommendations of a scientific professional institution."

Keywords: indicator gases, carbon monoxide, coal mine, explosion, fire, write-off, accident site, explosion-proof bulkheads

1. Introduction

In 2023, three previously isolated exogenous fires happened in the mines of Ukraine in the conditions of the Pokrovske and Pershotravenske mines that had to be extinguished and then written off. These fires occurred as a result of explosions of methane-air mixture in the workings of excavation sites of the southern wall 11, block 10, and of the northern "bis" wall 9, block 10 in the Pokrovske mine and in the workings of the wall 586 in the Yuvileyna mine of the PJSC "DTEK Pavlogradvugillia".

In accordance with clause 1, chapter 5 of section IX of the Normative Legal Act on Labor Potection (NLALP) 10.0-1.01-10 "Safety rules in coal mines" (hereinafter SR) [1] and clause 5.4.1 of the Governing Document (GD) 12.01.401-96 "Endogenous fires in coal mines of Donbas. Warning and extinguishing. Instruction" [2]

(hereinafter "Endogenous fires..."), all isolated endogenous and exogenous underground fires must be extinguished and written off. It is permitted to begin restoration and operational work in fire-extinguished areas only after the fire has been written off by a commission created by the employer, with the participation of representatives of the territorial bodies of the State Labor Service, Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NANU), as a specialized branch institute, and the State Paramilitary Mine-Rescue Service (SPMRS) of Ukraine.

Thus, according to clause 5.4.2 of the GD 12.01.401-96 "Endogenous fires..." [2] the signs that the fire has been extinguished are:

1. Hydrogen (H_2) and carbon monoxide (CO) in air samples taken from the fire site are absent or their content is not higher than the background values;

2. The temperature of the coal in the hotbed of fire is below the critical value characteristic for this mine layer;

3. The temperature of air and water flowing out from the isolated space does not exceed the values typical for the isolated workings of this horizon by more than 3–5 degrees.

According to clause 5.4.3. of the GD 12.01.401-96 "Endogenous fires ..." [2], control observations of the fire areas where further coal extraction or any other works (dismantling of equipment, removal of metal supports, etc.) are planned, must be carried out during not less than two months from the moment of reduction of the level of background content or full disappearance of carbon monoxide and hydrogen in the mine air samples. Sampling should be done every 5 days. That is, content of CO and H_2 in the isolated space should not exceed the background value for at least two to three months, which is usually rarely observed in practice.

The purpose of this work was to analyze the regulatory requirements for the safe concentration of carbon monoxide in the isolated space of the accident site for writing off a fire.

2. Methods

To achieve the purpose, it was necessary to perform an analysis of determining and to establish the dynamics of changes in the background concentrations of carbon monoxide and hydrogen, as indicator gases, in the isolated space of the accident site of the southern wall 11, block 10 in the Pokrovske mine, and in the workings of the wall 586 in the Yuvileyna mine.

3. Results and discussion

Analysis of the determination and dynamics of changes in the background concentrations of carbon monoxide and hydrogen, as indicator gases, in the conditions of the Pokrovske mine.

On February 5, 2020, at 2:15 p.m., a fire broke out in PJSC "Pokrovske" mine in the southern "bis" belt road 11 of the block 10 at a distance of approximately 30 m from its connection with the southern wall 11, block 10 along the movement of the outlet ventilation air stream. In the process of its extinguishing, methane flares began

to occur in the mined-out space, with varying frequency and increasing power. In this regard, a decision was made to stop active firefighting, to withdraw all rescuers from the workings of the excavation site of the southern wall 11, block 10 and to isolate the fire at a far safe distance. For this purpose, the work on the construction of one explosion-proof bulkhead (hereinafter EPB) from gypsum and two EPBs from "Bi-Support" was completed on February 8, 2020 during the second shift. The following bulkheads were erected: EPB No. 1 (made of gypsum) with three holes was erected in the mount passage of the southern wall 11 of the block 10; EPB No. 2 ("Bi-Support") with two holes was erected in the southern "bis" belt road 11of the block 10 and EPB No. 3 ("Bi-Support") with three slots was erected in the air roadway of the southern wall 11of the block 10. The works on closing the slots in the EPB, regulating and removing the depression from the volume of the isolated space of the mine workings of the excavation site of the southern wall 11, block 10 were completed on 08.02.2020 at 20:00 hours.

Composition of the mine atmosphere in the isolated space was checked by remote sampling of mine air through explosion-proof bulkheads. The samples were analyzed for the content of methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), carbon monoxide (CO) and hydrogen (H_2) in a gas analytical laboratory. In the period from 09.02.2020 to 16.02.2020 , samples were taken four times a day, from 17.02.2020 to 22.02.2020 , samples were taken once a day, and then approximately once a decade.

The observations showed that, fresh air flows from operating mine workings to the isolated space through the EPB №2 and EPB №3, and gas-air mixture flows from the isolated space to the operating mine workings through the EPB №1. Therefore, the results of the CO content observations at the EPB No. 1 were taken for the analysis of dynamics of the CO concentration in the isolated space.

In the isolated space, the inertization of the mine atmosphere began after the closure of the holes in EPB №1, EPB №2, and EPB №3 on 08.02.2020 and lasted approximately until 02.03.2020 (Table 1). During this period, concentration of methane (CH_4) and carbon dioxide (CO_2) in the outlet ventilation air stream from the isolated space increased from 0.8% to 72% and from 0.8% to 3.7%, respectively, and the content of oxygen (O_2) and carbon monoxide (CO) decreased from 19.7% to 1.3% and from 0.35% to 0.0003–0.0004%, respectively.

Further, after 01.05.2020, concentration of carbon monoxide (CO) in the atmosphere of the isolated space varied from 0% to 0.0015% (see Table 1). During this period, 96 determinations of the concentration of carbon monoxide (CO) in the atmosphere of the isolated space were made. The concentration of carbon monoxide (CO) in the range from 0% to 0.0005% was recorded in 48 samples, in the range from 0.0006% to 0.001% was recorded in 35 samples, and in the range from 0.0011% to 0.0015% was recorded in 13 samples.

Analysis of the dynamics of CO concentration in the atmosphere of the isolated space showed that the content of CO has a tendency to decrease without any apparent regularity [3–8]. But at the same time, the fluctuations of the values are very large. Thus, on 20.07.2020, the CO concentration was 0.0001%, and 10 days later, on 30.07.2020, it increased 11 times and amounted to 0.0011%. Then it decreased 11

times, and on 08.08.2020 it was again 0.0001%, and in 11 days, on 19.08.2020, it increased again and was 0.0012% (see table 1).

During the period from 02.01.2023 to 12.05.2023, the CO concentration in the twelve selected samples varied in the range from 0.0001% to 0.0007%. Such concentrations indicate that the oxidation (burning) process in the isolated space has stopped. The content of carbon monoxide in the mine atmosphere of the isolated space is significantly lower than the norm permitted by the SR [1] for mine workings of coal mines.

Table 1 – Results of determining the composition of the mine atmosphere in the isolated space for the EPB No. 1, which were obtained in the mount passage of the southern wall 11, block 10 of the "Pokrovske" mine

Date of sampling	Time	CH_4,%	O_2,%	CO,%
11.12.22	02:40	15.0	16.4	0.0010
21.12.22	02:40	15.0	16.4	0.0006
02.01.23	02:40	14.7	16.5	0.0006
11.01.23	02:40	17.0	16.5	0.0007
25.01.23	02:40	13.0	17.1	0.0006
14.02.23	02:40	15.0	16.9	0.0004
26.02.23	20:40	19.0	16.3	0.0003
08.03.23	02:40	21.0	15.3	0.0005
17.03.23	06:40	15.0	15.2	0.0002
29.03.23	06:40	15.0	15.7	0.0001
07.04.23	06:40	19.0	16.5	0.0006
17.04.23	08:15	17.0	15.0	0.0004
26.04.23	08:15	13.1	12.8	0.0001
12.05.23	08:15	13.0	18.7	0.0001

Despite the reduction of CO content in the mine atmosphere of the isolated space below the norm permitted by the SR [1] for the operating mine workings of coal mines, writing off the fire is impossible if to follow the requirements of clauses 5.4.2 and 5.4.3 of the GD 12.01.401 - 96 "Endogenous fires..." [2]. Since to write off the fire, it is necessary that content of carbon monoxide decrease to the level of the background value and then does not exceed it for at least two months.

The analysis of the results of the determination of the background concentration of carbon monoxide in mine workings of the southern wall 11, block 10 of the "Pokrovske" mine showed that the background concentration of CO in the outlet ventilation air stream in the stope working, the excavation area and in the degassing gas pipeline was determined on 12.03.2023 and 18.03.2023 according to " Methodology for determining the background content of carbon monoxide and hydrogen in mine workings of Donbas mines" (hereinafter the "Methodology...") (Appendix I to the GD 12.01.401-96 "Endogenous fires..." [2]). Approximately 150 m of excavation field was mined by longwalling. The results of the CO content analysis of the samples of the mine atmosphere in the workings of the excavation site of the southern wall, block 10 are shown in Table 2.

Table 2 – Results of the CO content analysis of samples of the mine atmosphere in the workings of the excavation site of the southern wall 11, block 10

Date of sampling	Location of sampling	CO concentration, %
March 12, 2019	Outlet stream from the southern wall 11, block 10	0.0004
		0.0002
		0.0002
	Outlet stream from the excavation site of the southern wall 11, block 10	0.0002
		0.0003
		0.0004
	Degassing pipeline of the southern wall 11, block 10	0.0004
		0.0005
		0.0005
March 14, 2019	Outlet stream from the southern wall 11, block 10	0.0002
		0.0001
		0.0002
	Outlet stream from the excavation site of the southern wall 11, block 10	0.0003
		0.0003
		0.0004
	Degassing pipeline of the southern wall 11, block 10	0.0004
		0.0004
		0.0004
March 18, 2019	Outlet stream from the southern wall 11, block 10	0.0003
		0.0002
		0.0001
	Outlet stream from the excavation site of the southern wall 11, block 10	0.0001
		0.0002
		0.0004
	Degassing pipeline of the southern wall 11, block 10	0.0008
		0.0005
		0.0007

In accordance with the requirements of the "Methodology...", the maximum values of the average volume fractions of carbon monoxide from one of the three days of the observations are taken as the background. As a result of calculations performed in accordance with the requirements of the "Methodology...", the following background values of the volume fraction of carbon monoxide were adopted. Concentration in the outlet stream from the southern wall 11, block 10 is equal to 0.00027%. Concentration in the outlet stream from the excavation site of the southern wall, block 10 is equal to 0.00077%. Concentration in degassing pipeline of the southern wall 11, block 10 is equal to 0.00067%.

Analysis of the results of determining background values of CO concentration showed that when they were determined, the actual CO concentration exceeded the background value. For example, the background value of the CO concentration in the outlet stream from the excavation site of the southern wall 11, block 10 was 0.00033. At the same time, on each of the observation days, the actual CO concentration of at least one of the three selected samples was higher than the background concentration (see Table 2). At the same time, no visible regularity in the dynamics of concentra-

tion in the operating mine workings was observed. Thus, on March 12, 2019, concentration of CO in the outlet stream from the extraction site varied from 0.0002% to 0.0004% within one hour, and on March 18, 2019, at a sampling interval of three hours, it varied from 0.0001% to 0.0004% (see table 2).

In accordance with the requirements of clauses 5.4.2 and 5.4.3 of the GD 12.01.401-96 E "Endogenous fires..." [2], in order to write off the fire in the isolated accident area of the southern wall 11, block 10, it is necessary that the content of carbon monoxide should decrease to the background level, which is equal to 0.00033% and then would not exceed this value for at least two months. Since the analysis of the samples is carried out with accuracy to the fourth digit, it is practically impossible to fulfill this requirement due to the fact that even when the background value of the CO concentration in the outlet stream of the site was determined during seven days actual CO concentration in three of the nine samples taken was higher than background by 0.00033% and was approximately 0.004%.

In the isolated space of the southern wall 11, block 10 of the "Pokrovske" mine in the period from 02.01.2023 to 12.05.2023, that is, during four months, the concentration of CO in only five of the twelve selected samples was lower than the background value, and in the remaining seven samples the concentration of CO varied from 0.0% (two samples) to 0.0007% (in one sample, see Table 1). The analysis of the second accident site was performed after the explosion happened in the "Yuvileina" mine of the "Pershotravenske" Mine Management of the DTEK "Pavlogradvugillia". On July 17, 2023, at 02:00 a.m., there was an explosion of methane-air mixture in the mine workings of the wall 586. At the time of the accident, people were evacuated from the mine, ventilation well No. 1 ВЦ-25М, ventilation well No. 3 ВО-21-14Д were operating in normal ventilation mode. Smoke was coming from the headgear part of the ventilation well No. 3, which was used for descending and ascending people in normal technological mode. Electricity to the accident site and along the direction of the outlet air flowing was turned off. Gas suction unit - ВМЦГ-7М (horizontal centrifugal fan), which was installed in the mother entry 586, was also disconnected. The underground degassing unit (UDU) worked in normal mode. Localization of the fire was carried out with the help of screw water sprinkler SWS-1 on the eastern drainage roadway No. 2 near the connection with the air break-through to the ventilation well No. 3; SWS-1 was installed at the entrance of the west main haulage roadway (WMHR), horizon 410m, the connection of which was planned in the event of a fire spreading to the WMHR, horizon 410 m.

To extinguish the fire, measures were taken on the eastern roll-off cross-slope No. 2 and the eastern drainage roadway No. 2, which allowed work to be carried out in the chamber of the ВМЦГ-7 of the mother entry 586, and in the mother entry 586 in connection with the eastern drainage roadway No. 2. The conditions under which the accident area was provided with the required amount of air and the absence of maximum permitted concentrations of CH_4 in the fire made it possible to isolate the accident site within its boundaries by erecting three explosion-proof bulkheads with subsequent flooding of the connection of the wall 586 with the boundary entry 586-bis. The places where the bulkheads were installed were as follows: explosion-proof

bulkhead EPB No. 9 - in mount passage 586 (chamber of the ВМЦГ-7М); explosion-proof bulkhead EPB No. 10 - in mother entry 586 before the connection with the eastern drainage roadway No. 2 and explosion-proof bulkhead EPB No. 11 - in boundary entry 586-bis. Feeder from the eastern haulage crosscut No. 2 to the mother entry 586 and the drop from the eastern conveyor crosscut No. 2 to the mother entry 586 was sealed with a gypsum solution.

When investigating the causes of the explosion of methane-air mixtures and the subsequent fire at the Yuvileyna mine, the expert commission also investigated the concentration of indicator gases at the accident site using regulatory and experimental methods [4, 5, 9, 10]. The state and characteristics of the fire at the accident site were determined by characteristics of indicator gases using the known methods, [10–14]. The obtained dynamics of changes in the concentrations of the main indicator gases based on the air samples taken at the accident site during the final period of extinguishing the fire at the Yuvileyna mine of the "Pershotravenske" Mine Management of the DTEK "Pavlogradvugillia" is shown in Table 3.

Table 3 – Dynamics of changes in concentrations of tracer gases during fire extinguishing works at the "Yuvileyna" mine

Date of sampling	Average daily indicator gas concentrations								
	Point № 12			Point № 14			Point № 18		
	CO, %	H_2, %	CH_4, %	CO, %	H_2, %	CH_4, %	CO, %	H_2, %	CH_4, %
30.11.23	0.1997	0.0065	12.2	0.1959	0.0062	12.0	0.2188	0.0063	12.4
01.12.23	0.1804	0.0045	15.7	0.1871	0.0036	15.0	0.1836	0.0040	16.0
05.12.23	0.2047	0.0116	11.5	0.1700	0.0099	13.9	0.2677	0.0063	13.4
10.12.23	0.0505	0.0000	12.7	0.0662	0.0000	13.2	0.0557	0.0600	14.9
15.12.23	0.0205	0.0011	20.7	0.0177	0.0012	18.6	0.0188	0.0016	19.2
20.12.23	0.0714	0.0039	15.1	0.0722	0.0035	15.4	0.0745	0.0042	14.7
22.12.23	0.0376	0.0034	16.1	0.0386	0.0028	15.0	0.0367	0.0029	15.3
23.12.23	0.0360	0.0020	19.0	0.0311	0.0015	19.3	0.0376	0.0020	20.4
24.12.23	0.0108	0.0016	18.8	0.0181	0.0013	18.0	0.0120	0.0013	18.7
25.12.23	0..0010	0.0021	15.3	0.0017	0.0018	15.1	0.0009	0.0012	18.1
26.12.23	0.0007	0.0036	17.8	0.0006	0.0028	14.2	0.0003	0.0036	13.6
27.12.23	0.0003	0.0006	9.2	0.0004	0.0015	17.8	0.0000	0.0015	12.1
29.12.23	0.0000	0.0007	13.1	0.0004	0.0003	10.6	0.0003	0.0010	19.1
30.12.24	0.0000	0.0006	16.7	0.0004	0.0007	17.0	0.0006	0.0010	17.9
01.01.24	0.0004	0.0005	12.4	0.0003	0.0010	11.5	0.0000	0.0005	12.1
03.01.24	0.0000	0.0001	14.0	0.0002	0.0004	11.9	0.0005	0.0001	11.9
04.01.24	0.0000	0.0004	23.4	0.0003	0.0005	16.0	0.0004	0.0005	19.4
05.01.24	0.0000	0.0010	21.8	0.0003	0.0006	17.2	0.0005	0.0005	18.8

The dynamics of changes in the concentration of tracer gases during the fire extinguishing at the Yuvileyna mine shows approximately the same patterns as for the conditions of the Pokrovske mine. So, in 3 locations, near explosion-proof bulkheads (points 12, 14, 18) during the period from (24–26).12.23, the CO concentration became less than dangerous (0.0017%), but sometimes it rose more than 0.0008 %. However, since the background values of the work site in the area of the wall 586 were not determined, their value was assumed to be conditionally 0.0006%. After a

2-week period with a concentration of less than 0.0009%, the fire was written off. At the same time, the temperature of the water flowing out from the accident site was lower than the typical values for the isolated mine workings of this horizon. It should be noted that the second and third signs, as a rule, cannot always be used or it is very difficult to apply them as additional ones when writing off a mine fire.

Since the background values of the indicator gases are not always determined in the locations of the future fire (it is not clear in advance where the fire can occur), it is obviously necessary to somewhat increase the number of locations for evaluating background values of CO and H_2 concentrations. Hence, there is a need to assess the concentrations of tracer gases not only at bulkheads and excavation sites, but also in other locations, for example, at the ends of degassing wells and in gas pipelines.

In addition, as it was previously mentioned, since sometimes before the occurrence of a fire, the background values in some areas were not determined, clarity is needed - by what criteria should be established that the fire has been extinguished. At the same time, as the experience of extinguishing fires showed, there is a need to specify more exactly the existing regulatory documents, namely, the methodology for determining the background values of indicator gases (and, in the absence of them, to accept some of their value based on other indicators) and the assessment that the fire is extinguished at the accident site during its extinguishing by the method of complete flooding [4, 8].

Thus, based on the analysis of the conducted experiments and the results of fire extinguishing, it is advisable to clarify the regulatory documents by adding a clause to the new regulatory document in the following wording: "When extinguishing a fire by a combined method by way of flooding an accident (excavation) site and at a decrease in the temperature of water and air from the isolated site, the period for reducing values of concentration of indicator gases to safe limits can be shortened, for example, by 2–3 times, upon agreement with the SPMRS and availability of recommendations of a scientific professional institution."

4. Conclusions

1. If to follow the requirements of clauses 5.4.2 6.4.3 of the GD 12.01.401-96 "Endogenous fires...", to write off a fire in the conditions of a highly productive operating wall is practically impossible.

2. The experience of extinguishing fires showed the need to specify in the existing regulatory documents more clearly the methodology for determining the background values of indicator gases and estimating fires extinguishment in mines. Thus, when updating this methodology, it is necessary to additionally provide for the determination of the content of indicator gases (CO, H_2, etc.) in gas pipelines and degassing wells. At the same time, it is necessary to clarify the locations and order of mine measurements, as well as the method of calculating the safe parameters of indicator gases for a possible write-off of the fire.

3. On the basis of the conducted experiments and the results of fire extinguishing, in our opinion, it is advisable to introduce a clarification by adding a clause to the new normative document in the following wording: "When extinguishing a fire by a

combined method by way of flooding the accident (excavation) site and at a decrease in the temperature of water and air from the isolated site, the period for reducing values of concentration of indicator gases to safe limits can be shortened, for example, by 2–3 times, upon agreement with the SPMRS and availability of recommendations of a scientific professional institution."

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ОБГРУНТУВАННЯ НОРМАТИВНИХ ВИМОГ ДО ВЕЛИЧИНИ КОНЦЕНТРАЦІЇ ОКСИДУ ВУГЛЕЦЮ В ІЗОЛЬОВАНОМУ ПРОСТОРІ АВАРІЙНОЇ ДІЛЯНКИ ПЕРЕД СПИСАННЯМ ШАХТНОЇ ПОЖЕЖІ

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Анотація. На шахтах України у 2023р. були три попередньо ізольовані екзогенні пожежі, які виникли в умовах шахтоуправлінь «Покровське» та «Першотравенське» і які було необхідно загасити, а потім списати. Ці пожежі виникли внаслідок вибухів метано-повітряної суміші у виробках виїмкових ділянок 11 південної лави блоку 10 та 9 північної «біс» лави блоку 10 на ШУ «Покровське» та у виробках 586 лави на шахті «Ювілейна» ПрАТ «ДТЕК Павлоградвугілля».

Метою цієї статті є аналіз нормативних вимог щодо безпечної величини концентрації оксиду вуглецю в ізольованому просторі аварійної ділянки для списання пожежі.

Методика. Для досягнення поставленої мети необхідно виконати аналіз визначення та встановити динаміку зміни фонових концентрацій оксиду вуглецю та водню, як індикаторних газів, в ізольованому просторі аварійної ділянки 11 південної лави блоку 10 ШУ «Покровське», а також у гірських виробках 586 лави на шахті «Ювілейна».

Обговорення. Оскільки фонові значення індикаторних газів в місцях майбутньої пожежі визначаються не завжди, то, мабуть, необхідно дещо розширити кількість місць оцінки фонових значень концентрацій CO і H_2. Звідси виникає необхідність оцінки концентрацій індикаторних газів біля перемичок і на виїмкових ділянках, але й біля інших місць, наприклад, у торцях дегазаційних свердловин і в газопроводах. При цьому необхідно уточнити місця та порядок шахтних вимірювань, а також методику розрахунку безпечних параметрів індикаторних газів, необхідних для можливого списання шахтної пожежі.

Практична значимість. На підставі аналізу проведених експериментів та результатів гасіння пожежі, були розроблені рекомендації щодо уточнення нормативних документів шляхом добавлення пункту до нового нормативного документа в такій редакції: «При гасінні пожежі комбінованим способом шляхом затоплення аварійної (виїмкової) ділянки за наявності зниження температури води та повітря із ізольованої ділянки за погодженням із ДВГРС та наявності рекомендацій наукової фахової установи термін зниження показників концентрації індикаторних газів до безпечних меж може бути скорочений, наприклад, у 2–3 рази».

Ключові слова: індикаторні гази, оксид вуглецю, вугільна шахта, вибух, пожежа, списання, аварійна ділянка, вибухостійкі перемички.