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**Antoshchenko M.,
Tarasov V.,
Zakharova O.**

ANALYSIS OF FIRE AND HAZARDOUS SITES (ZONES) IN COAL MINES AND THE CAUSES OF COAL SELF-IGNITION

Щорічно в шахтах України реєструють кілька десятків ендогенних пожеж. До теперішнього часу достовірно не встановлені гірничотехнічні і гірничо-геологічні чинники, що сприяють розвитку осередків самозаймання вугілля в характерних місцях (зонах) шахтного поля. Таким чином, об'єктом дослідження є процес самозаймання вугілля пожежонебезпечних ділянок (зон) у вугільних шахтах. Аналіз результатів розслідування ендогенних пожеж показав, що зонами самозаймання можуть бути скупчення втрат відбитого вугілля в робочому і виробленому просторі експлуатованих лав, і виробленому просторі зупинених вибоїв, крайові частини масиву розроблювального пласта або охоронних ціликів вугілля. А також зближені пласти, що підробляються і надробляються, очисні і протяжні гірничі виробки у зонах впливу геологічних порушень і поза ними, скупчення вугілля після його раптового викиду при газодинамічному явищі та порожнини цього викиду. За інших рівних умов фактор наявності тривалого контакту рудникового повітря зі скупченням відбитого вугілля є необхідною умовою виникнення осередків самозаймання. Показано, що при використанні возвратоточних схем провітрювання виймальних ділянок пластів пологого і похилого падіння, всі осередки пожеж виникали у зонах, прилеглих до відкатувальної або вентиляційної виробок. При цьому близько 70 % ендогенних пожеж при відпрацюванні крутоспадних пластів відбувалося поблизу відкотної виробки у зв'язку з накопиченням великих обсягів вугілля та подачею свіжого вентиляційного струменя повітря у робочий простір лави. Результати дослідження показують, що потужність пласта і кут його падіння не чинять безпосереднього впливу на накопичення відбитого вугілля. Вони не можуть бути основними факторами, що визначають осередки виникнення ендогенних пожеж, як це затверджено в нормативних документах.

Отримані результати сприятимуть удосконаленню нормативної бази безпечного відпрацьовування пластів, схильних до самозаймання, в тому числі і газоносних.

Ключові слова: *рудничне повітря, режим провітрювання, геологічні порушення, гірничий тиск, ендогенна пожежа.*

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1. Introduction

According to the current regulatory documents [1], anthracite formations are not dangerous for spontaneous combustion. Along with such a normatively accepted provision, there were cases [2, 3] of spontaneous combustion of anthracites under certain conditions of its storage in stacks or in mining. Spontaneous combustion of anthracites in the seam are not recorded.

In the period from 1979 to 2004, four endogenous fires were registered [4] in the developed space during mining of the anthracite layer l_3. The above facts indicate that all fossil fuels (including anthracites) are fuel and, under certain conditions, they may be prone to spontaneous combustion.

Currently, the least studied issue is the conditions for the occurrence of foci of spontaneous combustion of coal in different parts (zones) of the mine field. In many cases, mining and geological factors have not been reliably established [5], which contribute to the development of foci of spontaneous combustion of coal in characteristic places of the mine field. Studying this issue is an urgent task for the coal industry [6], since the health and life of miners working in underground conditions depends on it in many respects. Research in this direction helps to improve the regulatory framework for the safe mining of coal seams.

Thus, *the object of research* is the process of spontaneous combustion of coal from fire hazardous areas (zones) in coal mines.

The aim of research is establishment of mining and geological factors that contribute to the emergence of foci of spontaneous combustion of coal in characteristic places of the mine field.

2. Methods of research

The occurrence of foci of spontaneous combustion in different parts of the mine field is associated with mining and mining and geological conditions for coal. Spontaneous combustion processes occur under the influence of factors characteristic of these foci, which can significantly activate or inhibit these processes.

Endogenous fires occurred in almost all mine workings. Centers of spontaneous combustion occurred under the following circumstances:

– in the accumulation of coal losses during treatment operations or after their termination;

– in the marginal part of the array of the developed seam or abandoned solid blocks of coal;
– in close underworked or overworked formations;
– in treatment and long mine workings in the zone of influence of geological disturbances or outside them;
– in accumulations of coal after its release during a gas-dynamic phenomenon or in the cavity of this emission.

The sites of the possible occurrence of a source of endogenous fire in the mine field were considered, depending on mining and geological factors that could contribute to their formation.

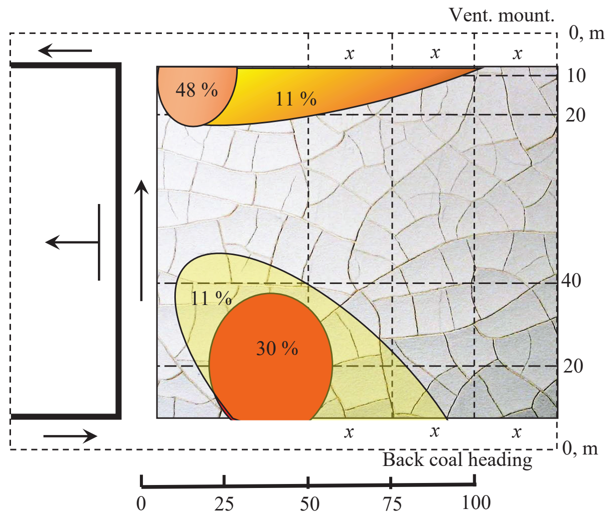
3. Research results and discussion

Accumulations of coal losses due to treatment operations can be located in different parts of exploited mining sites or the entire mine field. Usually chipped coal accumulates in the working space of the lava, and as the working face advances in its abandoned space. Outside of the exploited mining site, the losses of the chipped-out coal are located in the mined-out space of the stopped lavas. This indicates that the loss of chipped coal, as a source of foci of spontaneous combustion, can be found in existing mine workings, as well as unsupported and not actively ventilated. The ventilation mode of the mine workings determines, on the one hand, the conditions of oxygen inflow to possible foci of spontaneous combustion of chipped coal, and on the other hand, the heat transfer of oxidative processes.

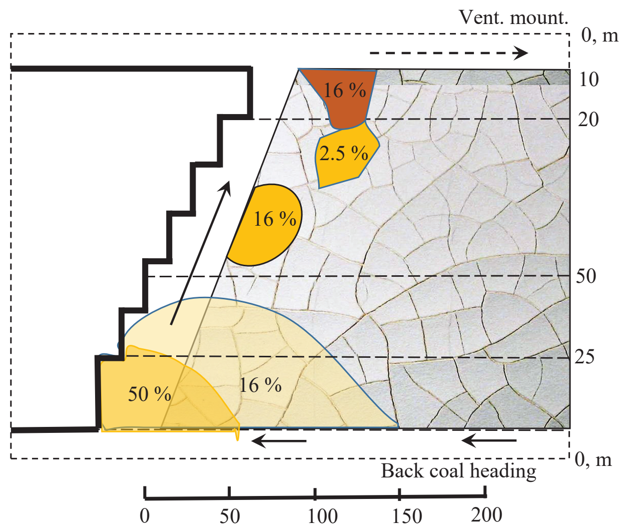
In this case, the direction of spontaneous combustion processes depends on the contact mode of the mine atmosphere with the broken coal. With the prevailing heat transfer, they do not receive further development and the formation of foci of spontaneous combustion does not occur. If, due to the movement of the air flow, heat is not fully carried out, then it accumulates in accumulations of broken coal. Perhaps dynamic equilibrium with the equality of heat storage and its removal. It can be violated by changing the ventilation mode or heat accumulation conditions.

Other things being equal, the factor of the presence of long-term contact of mine air with the accumulation of chipped coal is a necessary condition for the occurrence of foci of spontaneous combustion. It is possible only by accumulating heat during oxidative processes in accumulations of broken coal of certain sizes. The main condition for combustion is the flow of oxygen to the center of spontaneous combustion. Oxygen enters with the ventilation stream of air or with its leaks through the abandoned space of exploited and stopped lavas. The second necessary condition for the occurrence of foci of spontaneous combustion of broken coal is the presence of its accumulations of sufficient size. All other conditions being equal, only under the influence of oxygen inflow and sufficient dispersion of accumulations of broken coal confirm the occurrence of foci of spontaneous combustion, statistical data on endogenous fires serve [7] (Fig. 1).

In the case of reciprocal ventilation schemes for excavation of excavated sections of gently sloping and inclined slopes, all fire sources occurred in zones adjacent to the recoil or ventilation workings (Fig. 1, *a*). These zones are characterized by maximum losses of chipped-off coal during end operations and insufficient heat removal by only a limited number of air leaks.



a



b

Fig. 1. Fire hazard zones [7] with a reciprocal ventilation schemes: *a* – for the ventilation solid block of the excavation section (gentlu and inclined formations); *b* – on the abandoned space (steeply falling seam)

66 % of endogenous fires occurred near the recoil mine (Fig. 1, *b*), with direct-flow schemes for ventilating excavated sections of steep incidence. The technology of mining all steep seams provides for storing (accumulation) of coal at the recoil mine with subsequent loading through hatches into vehicles. Simultaneously with the accumulation of chipped coal in stores, a ventilation stream of air is passed through them to ventilate the bottom hole. The main reason for the occurrence of a source of endogenous fire in this case is the storage of a significant amount of coal (several tens of tons), which does not allow the necessary amount of heat to be removed by a ventilation stream of air. The occurrence of foci of spontaneous combustion in other parts of the worked-out space of the steep drop excavation site is associated with limited air leaks, which prevented the heat transfer.

The characteristic location of the zones of predominant occurrence of foci of spontaneous combustion of broken coal [7] indicates that the use of only reciprocal ventilation schemes according to [8] does not exclude the occurrence of emergency situations. The main factors

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preventing the occurrence of foci of spontaneous combustion of chipped coal, in the general case, are the reduction of its technological losses to a minimum and reliable isolation of accumulation sites. When developing steeply falling seams, the main cause of spontaneous combustion is the concentrated storage of a significant amount of coal and the supply of a ventilation air stream to it. These findings indicate that in the methods for assessing the fire hazard of the influence of interacting factors on the intensity of endogenous fires [9, 10], some adjustments are necessary. In particular, they relate to the use in the analysis of incidents of spontaneous combustion of coal accumulations of coal seam thickness (t) and angle of incidence (b). These parameters do not directly affect the occurrence of foci of spontaneous combustion in coal accumulations. The seam thickness can only indirectly, and then not fully, affects the thickness of the coal loss layer. The self-ignition of coal accumulations during mining of steep fall seams is caused, in almost 70 % of cases, by the technology of their mining and coal storing. The incidence angle does not have a practical effect on the amount of coal in stores. Its accumulation is directly related to the productivity of the extraction site and the regime of loading coal into vehicles.

A necessary condition for the nucleation of centers of spontaneous combustion in zones of influence of geological disturbances, as in the case of accumulation of chipped coal, is the contact of the mine atmosphere with the broken coal in these zones. About 30 % of endogenous fires occurred in zones of influence of geological disturbances, in which coal is dispersed and has an increased reaction surface. Foci of spontaneous combustion occur, as a rule, after removal of the bottom of the output from the violation. This is due to the softening of finely ground coal and the appearance of cracks through which air is allowed to enter the formation. The development of the heating process is accompanied by a smoothly flowing mass transfer in the loosened part of the formation. A possible inducer of air movement in a loosened fractured medium formed near the mine workings contour is thermal depression [11].

It is established [12] that the incubation period of spontaneous combustion can be 1.5–2 times different from that calculated by laboratory studies. It is recommended that the critical temperature of coal in zones of geological disturbances be determined taking into account the configuration of coal accumulations and the conditions of heat and mass transfer during chemical oxidation reactions.

The likelihood of endogenous fires in zones of geological disturbances increases with increasing amplitude of the displacement of the formation and the concentration of oxygen in air leaks [13]. This also confirms that the root cause of the origin of spontaneous combustion centers is the degree of disturbance of coal and the possibility of its contact with the mine atmosphere.

The origin of spontaneous combustion centers, both in the zones of influence of geological disturbances and outside them, is promoted by the manifestation of increased rock pressure on the edge of the seam mass or left behind solid blocks of coal. Such fires arise in a coal seam squeezed out under the influence of increased reference rock pressure at depths of up to one meter from their exposed surface [14]. The size of the reference pressure zone depends on the thickness of the developed formation (m), its depth (n) and the strength properties of the abandoned rocks. The mechanism of air entry into the squeezed part of the reservoir and the factors determining this process have not been sufficiently studied to date. There is no consensus on this [14].

This situation is confirmed by diametrically opposite regulatory requirements for the abandonment of technological solid blocks of coal during mining of seams prone to spontaneous combustion. In some cases [15], it is proposed to reduce the fire hazard by means of aimless mining of formations with all preparation methods and development systems. In others [16], a reciprocal ventilation scheme is used with the inter-main solid blocks of coal remaining, which are not cut through by ventilation failures. Thus, the aerodynamic connection between the abandoned spaces of the exploited section and the stopped lavas decreased. Air for ventilation of the working face is supplied through conveyor production (upward ventilation). An air stream emanating from the lava is discharged along the ventilation outlet. In conjunction with the exhausted space, along with measurements of methane concentration, an analysis is made of gas samples coming from the exhausted space to detect carbon monoxide and other indicator gases in them. Thanks to this control, foci of spontaneous combustion in the abandoned space are detected at the initial stage of their occurrence and measures are taken to eliminate them. Due to the possibility of such control during the development of gas-bearing shallow seams, ignition and methane explosions do not occur in the abandoned space of the exploited lava. For this reason, when coal is prone to spontaneous combustion, the treatment faces are aired only with the use of return circuits. Difficulties in the application of such schemes appeared in the extraction of 5–6 thousand tons of coal per day, and in some cases it reached 10–15 thousand tons [16]. Difficulties consisted in compliance with regulatory requirements for air velocity and maximum methane concentration in the air stream emanating from the face. To ensure high productivity of excavation sites and compliance with safety requirements, technological schemes for multi-track preparation of excavation columns for the development of high-gas and self-igniting shallow coal seams are developed and implemented [17].

In the process of preparing for mining the excavation solid blocks along the strike, the inter-main coal solid blocks are cut through by ventilation faults. Depending on the length of the column, their number is 5–7 or more. Through these failures, an aerodynamic connection arose between the abandoned spaces of the extraction column and the previously worked lavas. The direction of air movement along the lava is changed from ascending to descending – air is supplied through the ventilation drift to ventilate the working face. From the abandoned space of the exploited site, methane through a ventilation blast in the solid block is flown by a stream of air leaks to the ventilation track below the next excavation column being prepared for mining, bypassing the active face. As a result, from the ventilation of the excavation sections, according to the reciprocal pattern, they switch to the combined one, in which the abandoned space in the section 100–150 m from the working face is constantly intensively ventilated.

Such technological schemes for the preparation and development of extraction columns, called «multi-track», were experimentally used in the mines of Kuzbass (Raspadskaya, Ulyanovskaya, Yubileinaya, etc. – Kemerovo Region of the Russian Federation) since 1999. After the transfer of the excavation sites on the combined method of ventilation in high-performance mines of Kuzbass, working flat and inclined coal seams with long columns along strike, methane explosions began to occur almost annually with catastrophic consequences [16].

Regulatory requirements for the prevention and suppression of underground endogenous fires in the mines of Kuzbass, the speed of movement of the working faces are regulated by values of more than 90 m/month. Actual is 200 h 300 m/month. Owing to such an intensity of treatment operations, the reference rock pressure on the edge parts of the coal solid blocks, including those contouring the worked out space, has substantially increased. In this case, mechanical pressure is performed by supporting rock pressure to deform and destroy coal in the marginal parts of the solid blocks. During this work, the temperature of coal inside the edge part at a depth of 4–5 m increases by 25–35 °C and more depending on the values of the reference rock pressure [16]. Through crushed coal into the edge of the formation, air can flow unhindered to heated and crushed coal during mechanical destruction. The process of its oxidation is accelerated. In the places where ventilation faults are interfaced with the exhausted space, coal during the mechanical destruction is heated to a temperature of at least 40–50 °C. When working out a mining column through each ventilation unit that cut through the inter-main solid block, air leaks that ventilate the worked out space are bypassed for one month. During such a period, as a result of air entering the coal heated inside the boundary part of the formation, its temperature during oxidation increases and can reach 100 °C and higher [16].

The sizes of foci of spontaneous combustion that arise and develop inside the crushed edge of the coal seam (solid block) usually do not exceed 0.2–0.3 m in diameter. For this reason, the amount of CO released into the ventilation crash is insignificant. In a significant amount of air (up to 500 m^3/min), which carries methane out of the developed lava space, the concentration of CO is below the sensitivity threshold of the analytical instruments used. After isolation of ventilation slots, the resulting hot spots of self-heating with hot coal in them are preserved, although due to the cessation of air intake, the temperature increase in them stops. After the transition to the development of the next, downstream excavation column, air leaks again begin to flow into the centers of self-heating of coal that have arisen and developed earlier, but from the ventilation track, through which a fresh stream is supplied to ventilate a new treatment face. As a result of the air entering the remaining foci with coal previously heated in them, the process of oxidation and self-heating is activated. If in any of the foci located in the marginal part of the inter-main solid block of the oxidation, the oxidation process passes into the stage of flame burning, then the fire enters the edge of the solid block, including in the ventilation unit. In a vent from a burning coal, methane is ignited and a methane explosion occurs in the worked out space of the working face. Due to the technological features of the excavation areas ventilated by the combined method, foci of coal self-heating and spontaneous combustion occurring in the marginal parts of the inter-solid block solid blocks remaining in the mined-out space, as a rule, are not detected. As a result, the foci of spontaneous combustion of coal arising in the worked-out space are unexpectedly manifested by methane explosions. It is not the predictability of the ongoing methane explosions that determines their catastrophic consequences, accompanied by group fatal industrial injuries [16].

The occurrence of foci of spontaneous combustion in adjacent underworked and overworked seam is caused by the contact of coal with oxygen from the mine atmosphere due to the penetration of air leaks under the influence of mine depression. The possibility of air leaks to adjacent layers must be considered individually for each specific case, taking into account:

- location of the adjacent layers relative to each other, the order of their development;
- formation of zones of movement of the abandoned rocks with a gap in their continuity;
- ventilation schemes of excavation sites and mine field wings and some other factors.

After sudden gas-dynamic phenomena, it is necessary to take measures to clean the discarded coal and isolate the cavity formed in the coal seam.

4. Conclusions

The conducted studies allow to draw the following conclusions regarding the impact on mining endogenous risk of mining and geological factors:

- in the case of reciprocal ventilation schemes for excavation of excavated sections of gently sloping and inclined fall formations, all foci of endogenous fires were located in areas adjacent to the recoil and ventilation openings, where the loss of chipped coal was maximal due to the end operations;
- used in Ukraine options for reciprocal ventilation schemes of excavation sites do not allow to effectively control the nucleation of foci of spontaneous combustion of coal in the worked out space of the exploited lava;
- during the development of steeply falling seams, about 70 % of endogenous fires occurred in the areas of stacked coal storing with active ventilation with an air stream;
- power of the developed formation and the angle of its fall do not belong to factors that directly determine the conditions for the occurrence of centers of spontaneous combustion in coal accumulations;
- probability of occurrence of endogenous fires in areas affected by geological disturbances increases with increasing amplitude of the displacement of the formation and the concentration of oxygen in air leaks;
- high speeds of movement of the working faces (200–300 m/month), with certain methods of preparation for the extraction of coal solid blocks and ventilation schemes of the excavation sections, contribute to the emergence of foci of self-heating and spontaneous combustion of coal in the edge of the solid blocks. In gas mines, this leads to unpredictable ignition and methane explosions in the exhausted space with catastrophic consequences. This experience is not reflected in the regulatory documents of Ukraine.

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The obtained results contribute to the improvement of the regulatory framework for the safe development of formations prone to spontaneous combustion, including gas-bearing ones.

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Antoshchenko Mykola, *Doctor of Technical Sciences, Professor, Department of Chemistry and Industrial Safety Measures, Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, e-mail: kaf.zfx.sti@gmail.com, ORCID: http://orcid.org/0000-0001-8901-8263*

Tarasov Vadym, *PhD, Associate Professor, Department of Chemistry and Industrial Safety Measures, Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, e-mail: vatarasov81@gmail.com, ORCID: http://orcid.org/0000-0003-3614-0913*

Zakharova Olha, *PhD, Associate Professor, Department of Chemistry and Industrial Safety Measures, Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, e-mail: rubej10@gmail.com, ORCID: http://orcid.org/0000-0002-3400-411X*