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Computerized Analytical System for Assessing Fire and Environmental Safety of Mines in the Karaganda Coal Basin

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Abstract

The problem of recognizing the early stage of self-ignition of coal is one of the most important for preventing endogenous fires in mines. Developed fires and possible subsequent explosions of the dust-gas-air mixture, in addition to accidents, can lead to serious environmental consequences in the area of the mine. Research and development of methods for determining the stages of self-heating of coal in the process of oxidation is still relevant for miners. The developed information and analytical system is based on the gas analysis method and is aimed at operational management of measures for fire protection of mines. The analytical unit of the system is based on previously performed experimental studies of the dependence of the self-heating temperature of coal on the ratio of the content of indicator fire gases in samples of the mine atmosphere. Information about the composition of the mining atmosphere can be obtained by direct sampling or through specially installed air monitoring sensors. It is possible to include the developed system in scientific and methodological documents on the prevention of endogenous fires for the Karaganda basin.

Keywords: Coal mine, Spontaneous combustion of coal, Early stage of spontaneous combustion, Environmental consequences, Assessment of endogenous fire hazard.

I. INTRODUCTION

Currently, coal is still used as one of the main sources of fossil fuels for metallurgy and thermal power plants. In the process of underground mining, spontaneous combustion of coal, subsequent fire and methane explosions entail serious emergency and environmental consequences.

It is experimentally and theoretically established that at the early stage of self-ignition of coal, the chemical oxidation reaction occurs in the temperature range from the critical to the ignition temperature of volatile substances (300-350C) released from coal [1,2]. At the stage of intensive oxidation and self-heating of coal, gaseous products are released that have a negative impact not only on the mine atmosphere. The mine's ventilation system releases hundreds of cubic meters of air per minute into the atmosphere of the mine's location, including harmful gases from fire stations [3].

The methods used and existing documents (instructions, manuals) often do not allow us to categorize the detected signs of self-heating of coal: low- temperature oxidation, self-heating, early stage of self- ignition, Gorenje or damping. In such situations, the temperature is the only criterion for correctly assessing the current stages of occurrence and development of endogenous fire. The "Manual..." [3] Provides a qualitative description of the process of spontaneous combustion of coal, where the boundaries of the above stages are determined by the temperature of the coal.

The most reliable value of the coal temperature at controlled points with detected signs of oxidative processes is provided by instrumental methods and devices for measuring it – contact or non- contact thermometers, thermal sensors, thermal imagers. In the absence of the possibility of instrumental measurements, the "Instruction" [4] Recommends and permits the use of indirect methods for determining the self-heating temperature of coal.

II. EXPERIMENTAL SECTION

Despite some criticism, the gas analysis method is accepted as the main method for evaluating oxidative processes and the possibility of preventing endogenous fire in the mine. That is why the basin regulations [4,5,6] clearly regulate the main procedures for controlling and preventing spontaneous combustion of coal based on the gas analysis method. The responsible attitude of employees of the fire services of the mines of the basin to the prescribed procedures to a certain extent ensured timely prevention and suppression of possible spontaneous combustion and the occurrence of endogenous fires.

However, the processes of coal oxidation and removal of gaseous products of coal oxidation into the atmosphere in mines occur constantly, which forces miners to install sensors to control the mine atmosphere when developing layers that are prone to spontaneous combustion. However, it is difficult to determine the stage of development of the oxidation process only based on information from sensors and detected signs of self-heating of coal. This is especially true for

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determining the temperature in inaccessible and hard-to-reach areas of controlled sites or objects: developed areas of active sites, isolated waste sites. It is possible that hotspots of self-heating or self-ignition may also occur in the spent isolated sections of adjacent mines [7].

Understanding this situation led to the initiative of employees of the Coal Department of JSC "ArcelorMittal Temirtau" to develop an information and analytical system for forecasting and preventing the development of endogenous fires in the mines of the basin [9]. As a result of this work, with the participation of the authors of this article, a computerized analytical system was developed to assess the endogenous fire hazard in the mine and, as a result, the environmental hazard in the surrounding area.

The analytical unit of the system is based on information about the quantitative content of fire indicator gases obtained from sensors monitoring the parameters of the mine atmosphere or by direct sampling of air at controlled points [7,8]. Calculations of the self-heating temperature of coal were carried out based on the results of previously performed experimental studies in the Karaganda Department of the all-Union research Institute of mining and rescue (VNIIGD). Using modern mathematical-statistical and software tools for processing experimental studies, equations for the dependence of the temperature of self-heating of coal in oxidative processes on the quantitative content of fire indicator gases or their ratios were obtained for the first time.

It is the concentrations of gases, their ratios in the mine atmosphere of the controlled object and the temperatures calculated from them that were accepted as criteria for evaluating endogenous fire hazard.

The main stages (procedures) of functioning of the information and analytical system in the online mode are as follows:

Obtaining information about the concentration of gases in the mine atmosphere from the installed sensors of the control system or from the results of laboratory analysis of specially selected air samples;

introduction to the database in EXCEL table processor format of information about the composition of the mine atmosphere of the controlled area (or object) for the content of gases by dates (if necessary and time): carbon dioxide CO_2, oxygen O_2, carbon monoxide CO, hydrogen H_2, methane CH_4;

using the developed software tools for implementing criteria models, information is processed and output to the monitor of the dynamics of changes in the temperature of self -heating of coal;

Based on the analysis of the process dynamics, the endogenous fire hazard is assessed at the controlled site or object.

III. RESULT

To illustrate the use of the developed system for the analysis and evaluation of spontaneous combustion of coal the following is the source information according to the analysis of the mine atmosphere at the facility's No. 1 conveyor incline mine them. Kostenko for the period from 06.03.2018 to 16.03.2018

After entering and checking information on the composition of the gases in the mine atmosphere, the system offers to display the desired graph of the dynamics of changes in fire indicator gases and temperature from the menu shown in figure 2. Graphs of changes in gas concentration show, in General, the dynamics of the process of coal oxidation. For the analysis of the self-heating stage of coal, the most informative graphs of temperature changes and endogenous fire hazard assessment are provided. Figure 3 shows graphs of changes in the self-heating temperature of coal for different ratios of fire indicator gases.

	A	B	C	D	E	F	G	H
1	Kostenko Conveyor slope K10 Object No. 1							
2	Date	CO2	O2	CO	H2	CH4	C2H4	C2H2
3	06.03.2018	0,09	18,9	0,072	0,02	2,01	12,2	5,55
4	07.03.2018	0,32	18,4	0,11	0,022	1,02	18,4	4,43
5	08.03.2018	0,42	15,8	0,102	0,033	0,98	21	5,02
6	09.03.2018	0,62	16,4	0,091	0,003	1,13	24,9	6,03
7	10.03.2018	0,63	18,3	0,368	0,054	0,17	35,8	6,05
8	10.03.2018	2,82	16,72	0,092	0,004	0,07	43,8	5,22
9	11.03.2018	1,91	17,04	0,381	0,582	0,38	0	0
10	13.03.2018	0,97	18,74	0,432	0,65	0,35	66	4,05
11	14.03.2018	1,61	18,3	0,308	0,054	0,17	85,9	5,01
12	16.03.2018	0,85	17,6	0,109	0,035	0,85	93,5	3,86
13								

Fig.1. Information on the results of laboratory analysis of mining atmosphere sampling

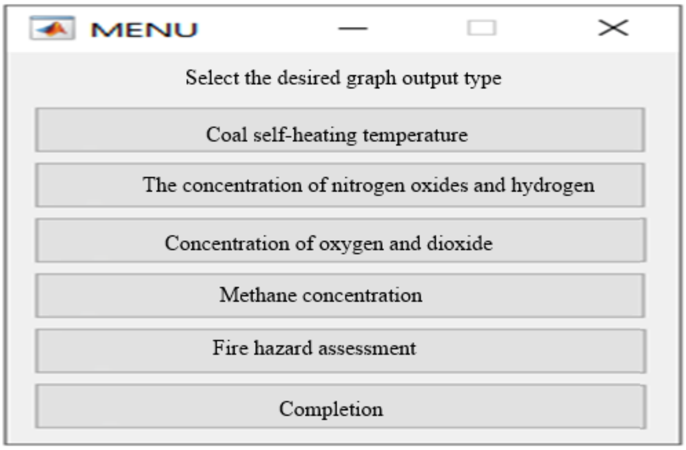

Fig. 2. Menu for selecting a graph of the dynamics of the self -heating process

The first graph is the self - heating temperature of the coal depending on the concentration of gases in the samples, which is calculated according to the following criteria:

ratio of CO oxide concentration to oxygen loss ($\boldsymbol{CO/-\Delta O_2}$);

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the ratio of the concentration of the oxide WITH the hydrogen content H_2;

Graham criterion (100*CO/ $-\Delta \boldsymbol{O_2}$);

Jung's criterion (CO2/ $-\Delta \boldsymbol{O_2}$).

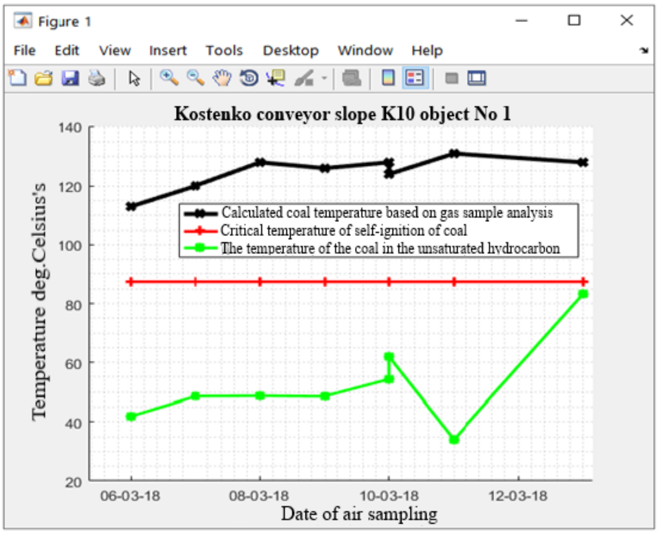

Fig.3. Graphs of changes in the self -heating temperature of coal

The dynamics of oxygen loss in the composition of the mining atmosphere is one of the obvious signs of the intensity of the oxidative process in the "coal- air oxygen" complex. The oxygen loss in the oxidation process in the analytical unit of the system is calculated in two ways.

The first is based on the calculated amount of oxygen when it is mechanically substituted for all other gases in the atmosphere, except oxygen (from those measured during sampling)

$$-\Delta O_2 = \left(100 - (CO + CO_2 + CH_4)\right) \cdot 0{,}209 - C(O_2)^{\phi}, \qquad (1)$$

where the first term of the expression represents the calculated amount of oxygen that should have been when it mechanically replaced oxide, carbon dioxide, methane , and hydrogen; 0.209 is the normal ratio of the oxygen content to the total volume of gases in the air (20,9:100=0,209);

O_2^{ϕ} – actual oxygen content in the sample, % vol.

The second method - determination of loss of oxygen content in the air sample in relation to the nitrogen (method VNIIGT)

$$-\Delta O_2 = 0.265 \cdot N_2 - O_2^{\phi}, \qquad (2)$$

where 0.265 is the normal ratio of oxygen content to nitrogen content in the air (20.9 : 79 = 0.265). The amount of nitrogen N_2 in the sample is determined by the difference 100 - ($CO+CO_2+O_2+H_2+CH_4$), % vol.

The second graph- a straight line, indicates the critical temperature of self-ignition of coal of a particular coal seam, is determined by a special method in the laboratory. The third graph is the calculated self -heating temperature of coal based on the content of unsaturated hydrocarbons. This method is accepted as one of the recommended methods in accordance with the basin regulatory document [4]. It follows from the graphs that for unsaturated hydrocarbons, the self-heating temperature of coal does not exceed the critical temperature, but by the end of the period it is approaching it. The calculated temperature for other fire indicator gas exceeds the critical temperature and reaches 130°, which is a concern when the concentration of carbon monoxide is a tenth of a percent.

IV. DISCUSSION

More informative and useful, in our opinion, should take the schedule of fire hazard assessment in figure 4, which is formed by the developed system , and allows a deeper understanding of the chemistry of the process of oxidation and self-heating of coal.

One of the signs of self-heating of coal is considered to be a steady lack of oxygen of the actual oxygen content in the samples of the mine atmosphere in comparison with its calculated value under the assumption of a simple mechanical substitution of impurities (methane, carbon oxide and dioxide, hydrogen) contained in the sample.

The lack of oxygen is calculated using the formulas (1) or (2) the critical lack of oxygen is determined for the main layers of the basin [6] and is included in the internal structure of the computer system.

Along with the critical lack of oxygen, the critical content of carbon dioxide in the samples for the reservoir layers was determined and entered into the system.

If the lack of oxygen and the content of carbon dioxide exceed the corresponding critical values for a certain period, hence there is an intensive absorption of oxygen; the oxidation stage can go into an early stage of spontaneous combustion.

This criterion is indicative and is practically used to assess endogenous fire hazard when detecting foci of oxidative processes.

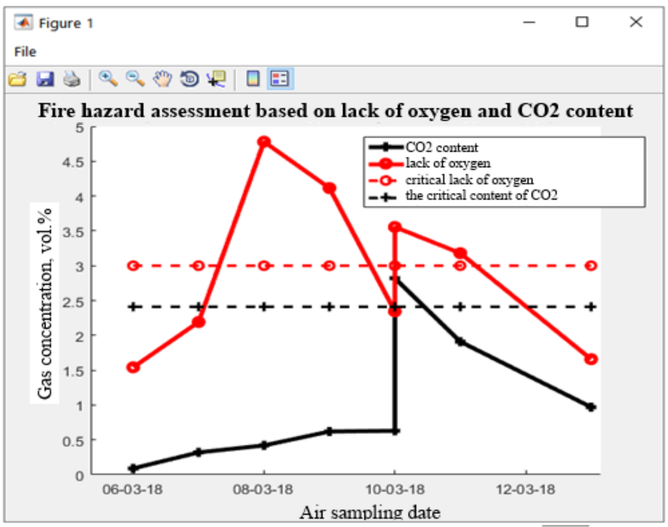

Fig.4. Output of information by the system for assessing endogenous fire hazard

The graphs in figure 4 show that on10.03.18 both criteria-lack of oxygen and carbon monoxide content exceed the critical values and characterize the possibility of an early stage of spontaneous combustion. The dynamics of the concentration of methane, carbon monoxide and are derived by the system for operational control of the explosiveness of the methane-air mixture in cases of rapid temperature increase and the threat of fire.

V. CONCLUSION

1. Endogenous fires in coal mines pose a risk for the occurrence of emergency explosive situations that paralyze the operation of the enterprise.

2. Released Gorenje products and possible explosion of the dust-gas-air mixture are carried out by the mine ventilation system into the surrounding atmosphere and negatively affect the ecology of the area.

3. The developed annotated analytical control system, based on empirical equations of the dependence of the self-heating temperature of coal on the ratios of indicator gases, allows us to determine the early stage of self-ignition and take timely measures to avoid the occurrence of endogenous fire and explosion.

4. With positive results of testing the system in real conditions, it is possible to include it in the scientific and methodological base of documents on safety and ecology for the mines of the basin.

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