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EXPERIMENTAL CONFIRMATION OF ACOUSTIC DIAGNOSTICS OF FIRES IN COAL BEDS*

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Abstract

This article described the experiment of acoustic diagnostics of endogenous fire in coal beds under industrial conditions. Using the bed example with active fire in it, the possibility of clearly identification of coal burning has been shown. The results of coal measurements in mine and in laboratory have been compared.

Keywords: acoustic diagnostics, coal bed, coal samples, endogenous fire, fire identification, mine conditions, signal spectrum

1. Introduction

One of the worst environmental problems is associated with endogenous fires in mines. Coal fires emit millions of tons of carbon dioxide, ash and other greenhouse gases into the atmosphere. One underground fire can make an almost lifeless desert on the surface of the earth with an area of more than 3 million m^2 (Kolmakov, 2005).

If you strictly follow the safety rules, the probability of fires completely disappears. However, firstly, it is impossible to completely eliminate the fire conditions (for example, it is technically difficult and expensive to completely remove dust and coal fires – it is unprofitable), and, secondly, underground endogenous fires occur not only where coal is extracted. We can name fires that have been going on for thousands of years, which occurred for reasons that are not precisely established in Tajikistan (Dolotov, 2002), China (Kuenzer,

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2007), Australia (Burning Mountain, 2020).

How do we assess the environmental consequences of endogenous fires in coal beds? First of all, there is a threat to human lives if miners die in a fire. But even if this issue is not considered, there still is a lot of complicated factors. The situations may be different: fire can collapse the mine, mine can be flooded with water or sand. Moreover, due to rising temperature of fire all physical and chemical processes are accelerated. As a result, mine water can turn into boiling water or even steam, the release of toxic gases will then increase by orders of magnitude, the supporting beams can collapse with the entire mountain range. Another issue is the ingress of combustion products in water pools or the surface. In this case, there are many problems that it is hardly possible to assess the damage from.

For example, China, the world's leading country in terms of coal production, accounted for 46.7% of the world's coal production in 2018 (British Petroleum, 2019), in recent years, 40%, and in some basins – up to 90% of working out beds are fire – hazardous.

Currently, the main areas of coal fires stretch along the coal mining belt of China, where more than 50 coal deposits have been identified and are affected by endogenous fires.

In order to effectively fight fires, it is necessary to perform corresponding actions in the early stages. And to do this, you need to act directly on the fire zone. Accordingly, it is necessary to determine the coordinates of the burning space with maximum accuracy.

Unfortunately, the most common methods of fire diagnostics based on measuring the concentration of indicator gases have significant disadvantages. These shortcomings do not allow to carry out fire-fighting measures with efficiency that guarantees timely suppression of the fire.

These disadvantages include ambiguity in the interpretation of the results of gas measurements and the real picture of appearance and propagation of the recorded gases. The main problem is the anisotropy of the rock mass permeability. Because of this, noticeable concentrations of indicator gases can be observed at a considerable distance (tens of kilometers) from the actual fire. However, even the most accurate sensors will not detect the danger at a distance of several meters from the burning space due to the lack of a channel that the combustion gases can pass through. Special studies conducted by the author (Borisenko, 2010) showed an unambiguous correlation of the gas conductivity of coal with its compression. It should also be noted that the registration of indicator gases from the daytime surface depends on weather conditions, and when snow falls, it becomes impossible at all.

2. Idea

Coal is a sedimentary rock, and therefore it is a multicomponent heterogeneous medium at the macroscopic and microscopic levels at the same time. It consists of many particles with different coefficients of thermal expansion. Due to either inhomogeneous heating of the rock, or difference in the values of the coefficients of thermal expansion and elastic properties of the minerals and aggregates composing the rock, thermal stresses occur in rocks (in our case, in coal) (Rzhevskij and Novik, 1978).

Inhomogeneity of the burning medium results in: differences in the thermophysical properties of the structural elements that make it up, in particular, thermal conductivity and thermal expansion, when heating accompanies burning, stresses arise at the boundaries of these elements. When the strength threshold is exceeded, such stresses develop into micro fractures, which, in turn, combine and merge into cracks. The direction of crack development is determined by two factors: the structure of the burning substance (the spatial distribution of its inhomogeneity) and the temperature gradient (the direction of heat supply). The development of cracks continues as heat is supplied.

To maintain burning in a stationary mode, preheating of the burning substance is required. In the case of parametric resonance, micro fractures merge into a single crack, which during germination provides a suction of the environment. At the time, when the cracks are developed, between its banks the continuous filling is absent, i.e. the part of the environment rushes in a newly formed vacuum with very high speed. And since most of cracks when burning germinate the temperature gradient – i.e. they come out on a burning surface, as a mobile part of the medium being hot gases and flames from the burning surface. Since the thermal conductivity of coal is low – lower than that of the host rocks, and does not exceed 3.44 W/ (m·K), the growth of cracks on the burning surface contributes to the heating of coal – increases the depth of heating – and thereby supports the combustion process.

When the distance between the crack banks reaches the value of the free path of the oxygen molecule, the crack also begins to contribute to the oxidation of the burning medium sections located in relative depth (at the distance of crack germination) from the direct combustion front. Thus, the combustion promotes itself into the burning media by cracking.

The occurrence of acoustic pulses during coal heating has already been noted by various authors (Borisenko, 2013; Nikolenko et al., 2020; Su et al., 2017).

Previously, we proposed a method for the diagnosis of endogenous fires in coal beds, based on registration of characteristic acoustic radiation. In (Borisenko, 2013) it is provided a schematic diagram of the implementation of this method. However, to date, the literature has not published the results of an experiment confirming the possibility of acoustic diagnostics of coal combustion in mine conditions. It should be explained that in real coal beds the situation is different compared to the laboratory conditions. First of all, the distances are longer, extraneous noise is present, and the presence of ambiguity of the acoustic wave propagation path (the presence of voids and zones with uneven mountain pressure).

So, as noted above, the coal burning is accompanied by cracking, resulting in acoustic radiation. However, the destruction of coal has multiple reasons besides burning. For example, coal sloughing or dynamic processes. It is logical to assume that the stresses that lead to the appearance and development of cracks for burning and compression by mountain pressure differ. Accordingly, the acoustic signals that occur during burning and mechanical action should also differ. Laboratory experiments conducted on samples of various coals confirm this. Therefore, it is important to obtain experimental confirmation of the possibility of acoustic identification of an underground endogenous fire in real conditions. This is the subject of this work.

3. Materials and methods

3.1. Method

Physical experiment was chosen as the main method for the research. This method allows getting accurate and reliable information and always preferred in the study.

The idea of the experiment is to register acoustic radiation in a coal bed in which an active endogenous fire takes place, and to identify the characteristic acoustic signals of a fire. The measuring system consisted of measuring elements, a signal transmission line, and a signal recording and processing unit.

Due to limitation of this manuscript size author doesn't provide the experimental layout. All the details can be find in (Borisenko, 2013).

3.2. Subject

Fire No. 64 in bed IV-V at the V. I. Lenin mine in the southern part of the Kuznetsk coal basin (Russian Federation) was chosen as subject for the experiment. The reason behind the choice is the presence of coking coal (CO brand), which is prone to spontaneous combustion, and is average in terms of metamorphism, coalification, and volatile matter output.

3.3. Methodology calibration and verification

The calibration and verification procedure were carry out before the experimental study. Laboratory tests were carried out on coal samples taken from the same bed (IV-V of the V. I. Lenin mine), in which the fire was monitored. During experiment coal samples were placed on basalt fiber suspensions to eliminate sounds caused by the contact with hard surface. The same measuring system used for mine measurements was installed on one side of the samples, and the opposite side of the samples was affected by the flame of a gas burner. When regime of independent burning of the samples was installed, the burner was switched off so as not to distort the acoustic pattern. Independent burning of samples was recorded for 5 minutes.

The results of verification are shown in Fig. 1. It is clearly seen from the figure that in the absence of a signal, the spectrum of the acoustic pattern recorded by the measuring system is quite uniform, without prominent peaks.

4. Results and discussion

In described experiment the distance between the burning space (the edge of the fire) and the installation site of the sensitive element of the measurement system was several tens of meters (June 7, 2008). The appearance of the measuring system is shown in Fig. 2.

In Figs. 3–5 the results of the experimental measurements are provides.

The spectrum of the acoustic situation registered during 5 minutes on the left side of the Eastern sloping track (direction to the fire source) is shown in Fig. 3.

For comparison, the acoustic situation was registered on the right side of the Eastern sloping track (direction from the fire source). Also, within 5 minutes. The spectrum of this measurement is shown in Fig. 4.

From the comparison of Fig. 3 and Fig. 4 it can be seen that the acoustic patterns in the same coal bed differ in the directions: to the fire and from the fire. The direction to the fire is characterized by the presence of peaks in the frequency range 1300 and 2000 Hz, while for the direction from the fire such peaks are not observed.

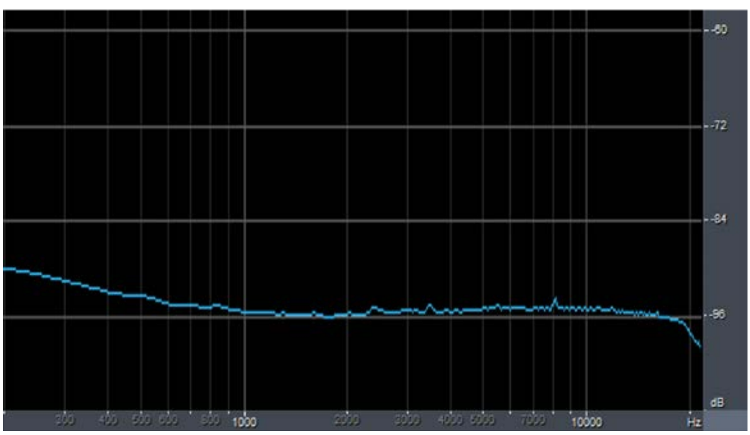

Fig.1. Spectrum of the acoustic pattern recorded by the measurement system in the absence of a fire signal

Fig.1. The appearance of the mine experiment

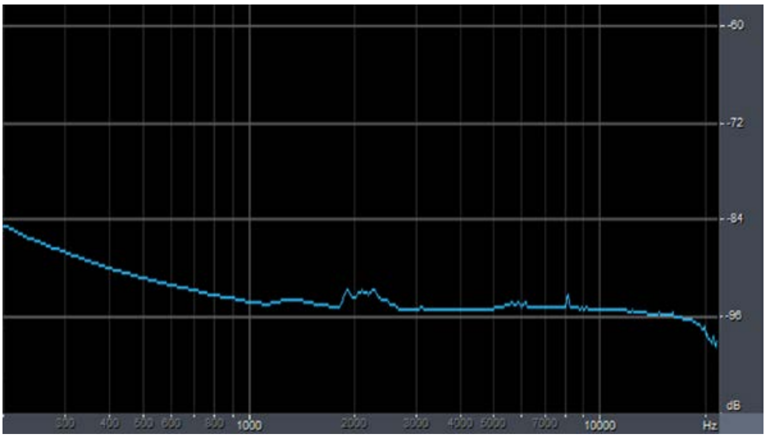

Fig.3. Spectrum of acoustic radiation registered in the coal bed under mine conditions in the direction to the fire

Two peaks dominate the spectrum of acoustic radiation that occurs in coal samples during their independent burning: at frequencies of 1300 and 2000 Hz. This clearly corresponds to the acoustic pattern recorded in the coal bed from the side of the fire. It should be noted that as the distance traveled increases, the signal weakens and the peaks dominating in laboratory conditions will be the only ones distinguishable over long distances in mine conditions. It should also be noted that the relative values of peaks at 1300 and 2000 Hz are different from mine measurements in the bed and from measurements on samples in the laboratory. This may be due to the fact that at lower frequencies (1300 Hz), the resulting cracks are characterized by a larger surface area than at 2000 Hz. Accordingly, the resulting acoustic pulses are more intense at 1300 Hz than at 2000 Hz. And since more intense pulses are realized less often than less intense ones, the total contribution of strong pulses to the spectrum of the entire acoustic picture is smaller.

Comparison of the acoustic pattern spectra recorded in the coal bed in the direction from the fire (where there is no burning) (fig. 4) and acoustic radiation that occurs in coal samples taken from this bed during independent combustion (Fig.5) shows the difference in signals. From this we can conclude that the character of the curve is also different.

Thus, in laboratory and mine conditions, the possibility of clear acoustic identification of a fire in coal beds by calibration on samples taken from these layers has been experimentally proved. A characteristic feature of fire identification is the presence of peaks at the same frequencies for the studied conditions (coking coal, southern Kuzbass) – 1300 and 2000 Hz.

The spectrum of the acoustic pattern recorded during independent burning of samples for 5 minutes is shown in Fig.5.

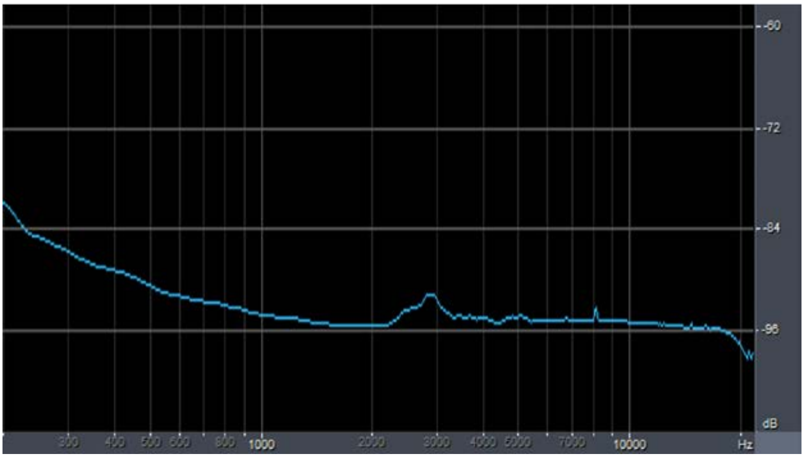

Fig.4. Spectrum of acoustic radiation registered in the coal bed under mine conditions in the direction from the fire

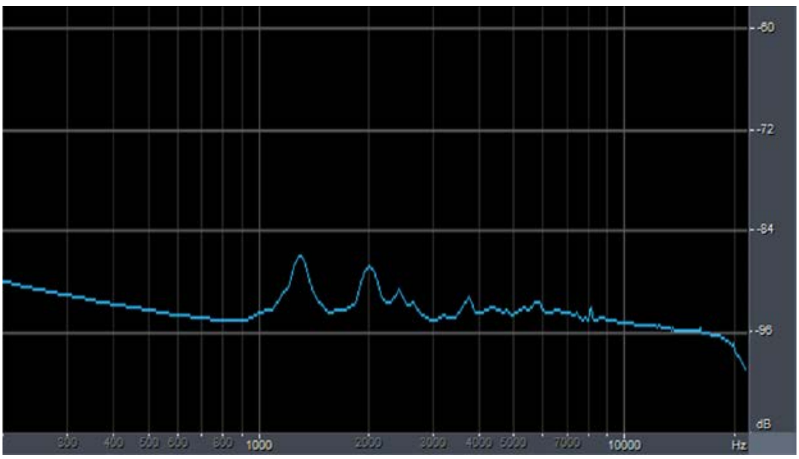

Fig.5. Spectrum of acoustic radiation, occurring at independent burning of coal samples in the laboratory

5. Conclusions

- A full-scale experiment was conducted on acoustic diagnostics of a fire in a coal bed in underground (mine) conditions.
- Laboratory experiments were carried out on coal samples taken from the bed where an active fire is taking place.
- The characteristics of acoustic signals obtained on coal samples and in the bed from which these samples were taken in the mine were compared.
- A characteristic feature of coal burning that is an acoustic sign of fire has been identified.

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