IMAGING AND CHEMICAL METHODS FOR PREVENTING THE RISK OF COAL SELF-IGNITION

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Abstract
Important information for drawing up the risk scenario and the plan for preventing spontaneous combustion in coal mines are provided by knowledge on the coal's self-ignition tendency gained from laboratory determinations carried out for establishing self-ignition parameters and for the classification of coal from this point of view.

This paper provides an analysis on the concerned preventive triangle: a classification on the self-ignition risk, applications of preventive methods in coal mining thermography and the instrumentation of inhibiting water solutions as measures for preventing coal self-ignition.

Keywords: coal, risk, spontaneous combustion, temperature, thermogram, inhibitors.

ВІЗУАЛІЗАЦІЯ ТА ХІМІЧНІ МЕТОДИ ДЛЯ ЗАПОБІГАННЯ РИЗИКУ САМОЗАЙМАННЯ ВУГІЛЛЯ

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Анотація
Апріорне знання ризику самозаймання шляхом лабораторних визначень параметрів самозаймання та класифікації вугілля з цієї точки зору, забезпечує необхідну інформацію для підготовки сценарію ризику та плану запобігання самозаймання у вугільних шахтах.

Ця робота спрямована на аналіз цього профілактичного тринома: класифікація ризику самозаймання, застосування методів запобігання при видобутку вугілля, термографії та контрольно-вимірювальних приладів водних розчинів з інгібіторами, як заходів щодо запобігання самозаймання вугілля.

Ключові слова: вугілля, ризик, самозаймання, температура, термограма, інгібітори.

2. INTRODUCTION

In the work environment, especially in underground mining works opened in coal layers, the danger of spontaneous combustion phenomenon is imminent if the operation does not comply with the security requirements from the Health and Safety document. This requirements involve the working environment temperature, ventilation parameters (ventilation scheme, non-optimized airflow, air speed), direction and speed of operation, method of operation and the rate of extraction of minerals substance.

The risk of self-ignition of coal represents the probability of generating a phenomenon of spontaneous combustion due to intrinsic and extrinsic factors that contribute to its emergence separately or combined. Depending on the laboratory method of determining in Romania are five groups of risk of self-ignition of coal.

Classic thermometer measurements applied underground does not always reflect the real situation of coal layer temperature, from the exploited space, or the surrounding rocks, from objective or subjective reasons of the work procedure application.

Contactless thermometer eliminates these drawbacks, enables automatic measurement of hot or cold temperature nuclei, thermal scanning, generating the possibility of drawing in the shortest time a thermal map.

Based on the thermal map the technical and organizational measures are taken in order to prevent the coal self-heating, using coal treatment process of inhibitory substances in the form of aerosol spray.

3. CLASSIFICATION OF COAL ON THE BASIS OF SELF-IGNITION RISK. METHODS AND TECHNOLOGIES FOR PREVENTION AND COMBAT

Self-ignition of coal represents a particular risk for mining industry and appealing to this notion used in the management of health and safety at work, the risk of self-ignition of the mineral substances, is classifying the carbonaceous substance in relation to the method of determining the laboratory, which corresponds to a function of classification (table 2.1):

- Method of determining the risk of self-ignition in gaseous oxygen environment with classification function: the temperature gradient ΔT/20′;
- Method of determining the risk of self-ignition in a liquid medium (perhydrol) function classification: the reaction rate v_r (^{0}C / min.).

Table 2.1

Group classification	The behavior of coal	
	in gaseous oxygen environment / the temperature gradient ΔT/20′	in a liquid medium (perhydrol) / the reaction rate v_r (^{0}C / min.).
Group *I*	Coal without risk of self-ignition, ΔT/20′ < 5°C/20′	Coal without risk of self-ignition, v_r < 3°C/min.
Group *II*	Coal with low risk of self-ignition, 5°C/20′ ≤ ΔT/20′ ≤ 20°C/20′	Coal with risk of self-ignition, 3°C/min ≤ v_r ≤ 10°C/min.
Group *III*	Coal with medium risk of self-ignition, 20°C/20′ ≤ ΔT/20′ ≤ 35°C/20′	Coal with pronounced risk of self-ignition, v_r >10^{0}C / min.
Group *IV*	Coal with high risk of self-ignition, 35°C/20′ ≤ ΔT/20′ ≤ 50°C/20′	-
Group *V*	Coal with pronounced risk of self-ignition, ΔT/20′ > 50°C/20′	-

Methods for prevention and combat are applied in order to avoid coal losses and its' contact with oxygen, for reducing heat accumulations and oxidation reactions (Bardocz, 1983).

a. Classical methods

Methods for preventing and fighting against spontaneous combustions, including the ones applied in case of top coal caving longwalls are the classic ones, namely: mud-filling, antipyrogenes substances treatment, foam usage, goaf sealing using insulation works.

i. Mud-filling

This method consists of inserting, using special installations, mixtures of substances, directly into the goaf. As materials, there were used in time the following: dry backfill, hydraulic backfill, clay pulp, fly ash pulp. In practice, there are used ash-water ratios of up to 1:10.

ii. Antipyrogenic substances

These substances ads3orb heat due to the decomposition of removal of hydrating water and reducing the oxygen adsorption surface. Cheap chemical substances, with powerful antipyrogenic effect, which contribute to the delay of spontaneous combustion are calcium chloride ($CaCl_2$) and sodium bicarbonate ($NaHCO_3$). Large applicability has only dry sodium bicarbonate, manually dispersed on the floor of the longwall.

In case of top coal caving longwalls, the influence area is relatively low, being limited to the floor of the longwall or of the galleries, areas located above, where coal is found, remaining untreated.

iii. Chemical foams

For preventing and fighting against spontaneous combustions are used two types of foams, mechanical foam and chemical foam (Matei et al., 2004).

Mechanical foam is obtained from air and water foamy solution, using special devices such as foam generators. In the mixing hopper is achieved a mixture of foam, fly ash, water and air, inserted directly into the goaf. The advantage of this mixture is that in retains part of the water from the mixture. In practice, this method is used only for combat, but due to low quantities (tens or hundreds of litres/longwall/month) rarely administrated it had a reduced effect upon spontaneous combustions.

Chemical foam is obtained from unique dust which in the presence of water forms a mass of reduced size bubbles, each one containing carbon dioxide. Gas (CO_2) is formed following the chemical reaction between substances which generate foam (acid and basic substances). In practice, due to the high price of unique dust, it is used only for fighting against spontaneous combustions. Unique dust is inserted into the goaf using the mud-filling installation (Michaylov, 1995).

iv. Insulation works

This method is used for prevention and combat purposes and consists in sealing the goaf or the fire area with insulation dams. Types of insulation construction used are dams from wood and clay, concrete, as well as masonry bricks.

Insulation dams are currently used, in time losing their insulation properties, reason for which it requires additional tightening measures.

2.2. Modern methods

2.2.1. Indirect prophylactic methods

These frame into the group of spontaneous combustion prevention methods and comprise the method for determining the coal self-ignition tendency and the method for monitoring longwalls using fire indexes (Cioclea et al., 1996).

Determination of the self-ignition tendency is a laboratory procedure which simulates in a very short time the phenomenon of coal self-ignition in the deposit, developed in a certain time period and is focusing on the temperature increase in an oxidant environment. Based on the self-ignition tendency determination, coal beds are classified.

The method for monitoring longwalls using fire indexes (Graham, Breathing, Ethylene and Acetylene) is based on the principle stating that in the oxidation process the concentration of carbon oxides increases and the oxygen content decreases. Through direct measurements are determined gas O_2, CO_2 and CO concentrations in the underground atmosphere, active or insulated and are collected air samples, and by the interpretation of results there may be appreciated the state in which a combustion phenomenon may be found.

2.2.2. Direct prophylactic methods

A large range of prevention methods are known: for reducing coal losses using water under pressure, for coal treatment using inhibiting chemical substances, for additional tightening of insulation constructions using advanced solution, for reducing air leakages through goafs, by using expandable foams, for nitrogen inertisation of goafs, in which, the option of appliance is conditioned by financial expenditures specific for each method. The simplest, fastest and cheapest method is the treatment of the goaf using chemical substances (Cioclea et al., 2008).

The reduction of coal losses is obtained through actions upon the coal bed using mechanical vibrations, blasting works in the seam or roof, directly and by displacement works using the injection of water under pressure.

For coal stuck in the goaf are used expandable foams (humid, chemical or aeromechanical) and the successful achievement of a inert nitrogen atmosphere (Mihaylov et Krilchev, 2008).

Chemical inhibiting substances are used for reducing the coal self-oxidation tendency. The hypothesis on the catalytic role of microelements from coal lays ground for the testings. Relevant results were obtained when using treatment technologies with water solutions 0.5% sprayed as aerosols into the mine workings, with trisodium phosphate (Na_3PO_4. $12H_2O$) or zinc chloride ($ZnCl_2$).

Nowadays, modern technique placed on the market thermal vision camers, configured also as firedamp-proof, using which there can be viewed thermal images in the coal bed or longwall.

2.3. Work environment monitoring using thermal vision cameras

The temperature of the coal bed or of the goaf is a parameter which is directly proportional with the development of the spontaneous combustion phenomenon. Coal is a bad heat conductor; it accumulates heat, thus increasing the temperature in the area (core) bringing along the intensification of the oxidation process, based on the process for oxygen sorption from the atmosphere.

Thermography (thermal-vision) is the measurement of the thermal field by recording infrared radiations and visualizing the distributing of temperature on the surfaces of the coal bed or of the goaf, by measuring IR radiations.

Thermal processes may be observed and analysed quickly the control routes main me efficiently managed with high resolution thermal images.

Currently, INCD-INSEMEX disposes of thermal vision cameras which are able to scan and view temperature fields at the level of the targeted object (Tomescu, Chiuzan, 2016).

Such equipment is Fluke TiX 500, 60 Hz, presented in Fig. 2.1. This Atex Thermal Imaging Camera offers the maximum level of safety in explosive atmospheres, ATEX Zone 1. Temperature measurement: -20^0 C to 650^{0}C.

Fig. 2.1. Thermal vision camera

By using this equipment there can be obtained not only the visualisation of temperature fields, but also the temperatures of targeted objects in a non-invasive manner. By focusing the infrared fascicle is obtained from the distance the temperature value of the chosen area, and by directing the device towards a certain area is instantly obtained its’ temperature spectrum. Within a coalface, during the monitoring period may be obtained a thermal image of the coal face – Fig. 2.2. In this figure weren’t noticed clear heating areas. Also, there may be tracked staff in the coal face, as presented in Fig. 2.3.

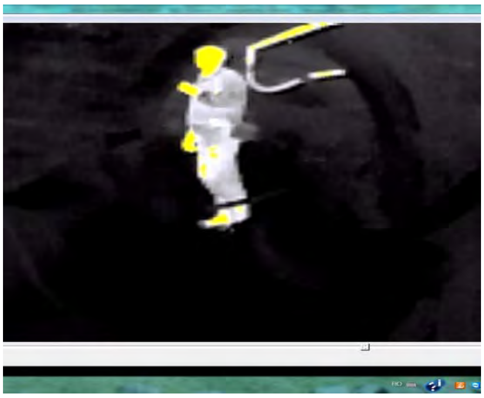

Fig. 2.2. Coalface – thermal imprint

Fig. 2.3. Coalface – human thermal imprint

If the conveyor increases in temperature due to friction, this phenomenon may also be tracked – Fig. 3.4, if there are overburdened electrical cables then their imprint may be obtained – Fig. 3.5.

Fig. 2.4. Coalface – conveyor thermal imprint

Fig. 2.5. Coalface – electrical cable thermal imprint

Fig. 2.6 presents the imprint of heated water from the coalface. In case of an in development self-heating phenomenon in the goaf or at the level of the undermined coal bed from the work sublevel, the discharged coal has a temperature which is higher than the normal one as presented in Fig. 2.7.(Tomescu et al. 2016)

Fig. 2.6. Coalface – heated water thermal imprint (50^0 C)

Fig. 2.7. Coalface – discharged heated coal thermal imprint (280^0 C)

If a self-heating phenomena is detected in the coal bed from the work sublevel, on the coal's surface occur areas with temperature higher than the normal one, as presented in Fig. 2.8.

Fig. 2.8. Coalface - coal from the massif thermal imprint

2.4. Coal prophylactic treatments with inhibitory sollutions and preventive technologies

2.4.1. Description of the installation for the production of aerosol inhibitor and work method

Method of preventing endogenous fires in coal mining is based on the circulation of very fine particles (micron range) of the solution of the inhibitory substance both in the exploited space, and stope, depending on the location of the instalation - following the direction of the air currnets movement.

The device for generating the aerosol A (Fig.2.9) is composed of a tank with a capacity of 200 liters (1), a spray for air and water (2) and the connecting hoses (3) to the compressed air network of the workplace and the tank that has inhibitory substance (5). Also, on the inlet of compressed air to the atomizer is mounted a valve (4).

The spray, by means of which the aerosol is made from the inhibitory substance, has the following parameters: operating pressure 0.3 ÷ 0.6 MPa, air consumption, 1.05 ÷ 0.8 m3 / min., the inhibitory solution consumption 0.8 ÷ 1 liter / min., the yield of transformation of the solution in the aerosol: 90 ÷ 100%.

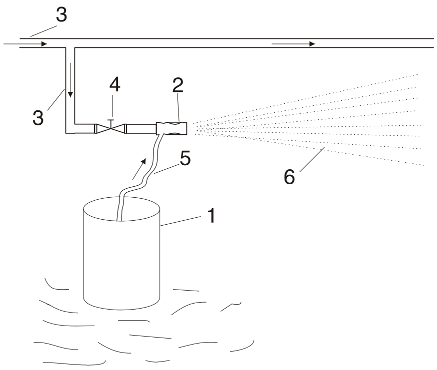

Fig. 2.9. Aerosol instalation

2.4.2. The technology of aerosol treatment

Due to the inhibitory properties posed by the phosphate in the oxidation-self-ignition of coal, the treatment with aerosol from the group "phosphates" of the exploited space and stope helps reduceing the risk of spontaneous combustion. Also as inhibiting substance is used the zinc chloride.

For the exploited space treatment, the ejector is mounted in the base gallery, where the aerosol format will be worn in the exploited space by air currents circulating in the area. However the ejector is mounted in the space exploited where were measured high concentrations of CO (over 0.1% vol.).

The ejector (Figure 2.10) will be placed at the height of 1 - 1.5 m from the mining work, being oriented towards the area to be treated with aerosols and will operate every point about 1 hour at least once a day (Toth, I., 2004) .

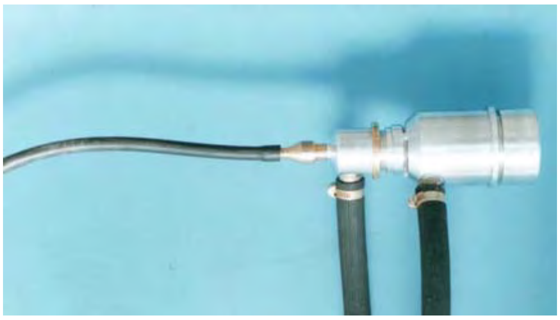

Fig.2.10. Spraying device

The spray device used is the main component of the instalation used to prevent spontaneous combustion technology applied in extracting selfheating minerals in general and coal in particular. The result of applying generalized technology to prevent spontaneous combustion was materialized by decreasing the number of phenomena of spontaneous combustion.

4. RESULTS OBTAINED AND DISCUSSION

a. Advantages and disadvantages of the thermal-vision technique:

- The main advantage of using the thermal vision technique is the fact that by using this method for determining the temperature, the time for investigating a longwall is decreased, it increases the safety in detecting heated areas, there may be determined temperatures of areas from the goaf located at larger distances and there can be developed thermal maps of large surfaces;
- The measurement equipment (thermal vision camera) does not emit harmful radiations for the operator or staff from mine workings. Thermal scanning is performed without direct contact with the mineral or surrounding rock, with the equipment or installation which is thermally assessed.
- Monitoring the work environment by thermal imaging is a non-invasive, non-destructive method, not intervening and influencing the coal within the coal bed, the investigated installation or phenomenon. Thermal imaging may be performed on machinery bodies in movement or in inaccessible areas and allows the assessment, from the thermal point of view, of electrical equipment/installations in operation or of overheated machinery bodies.
- The disadvantage of using this thermal-graphic technique is represented by the high costs for acquiring the tool, especially for the firedamp-proof construction.

3.2.The developed aerosol effects were multiple and have materialized in the following:

- The aerosol circulated in the exploited space covering the unexploited remaining coal;
- The suspended coal dust in the stope alignment was linked to aerosol, the workplace air clarifyed the few minutes after the start of applying the aerosol;
- In the case of the aerosol process during the blasting operation or immediately after the operation, the blasting gases, especially toxic ones were bound within a few minutes. In this way one can reduce the ventilation time after blasting operation;
- The aerosol spraying during its formation is cooling the area thereby contributing to the dissipation of heat which is formed during the spontaneous combustion.

5. CONCLUSION

The increase of the safety level of minerals in the underground environment and implicitly of the health of workers is performed by methods, types, technologies and schemes of classical or modern measurements for preventing the spontaneous combustion phenomenon.

In the open mining coal layers, the danger of spontaneous combustion phenomenon is imminent and is one of the major risk factors of coal mining industry, in addition to the released methane.

Depending on the method of determination in the laboratory, in Romania there are five risk groups for self-ignition of coal.

The thermometer without contact, using thermal imagers enables automatic measurement of hot or cold temperature nuclei, thermal scanning, viewing of the fields of temperature and temperature value of the target objects and generates the possibility of drawing in the shortest time a thermal maps.

Thermal maps are auxiliary tool for making technical and organizational measures to prevent the phenomenon of spontaneous combustion using coal treatment technology inhibitory substances sprayed with aerosol;

Work environment monitoring using thermal vision cameras allows real-time analyses before and after the interventions in the coal bed, goaf, in a good visual contact condition, in order to obtain useful information for investigation the evolution/involution of the spontaneous combustion phenomenon in time and for drawing up the thermal maps of the surface in the longwall.

The effects of thermal vision monitoring are the decrease of coal exploitation expenditures, the increase of the coal exploitation level and they improve the underground environment safety conditions.

Widespread application of these two methods of prevention leads to a decrease of endogenous fires, thereby increasing the degree of operational safety and thus a sustainable mining.

Gratitude

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