ASSESSMENT OF SUSCEPTIBILITY OF COAL TO SPONTANEOUS COMBUSTION IN OKR

OVĚŘOVÁNÍ NÁCHYLNOSTI UHLÍ K SAMOVZNÍCENÍ V OKR

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Abstract

Spontaneous combustion of coal mass represents a considerable health hazard of workers and endangering mining operations, which is often connected with a failure of coal mining and costs of endogenous fire suppression. Prompt recognition of spontaneous combustion plays a very important role in deep working coal seams prone to spontaneous combustion. The susceptibility of coal to a spontaneously combustible process is considered as a feature of coal mass that can be specified by a laboratory test. Since seventies of the last century in OKR (Ostrava-Karvina Coal Field) methods according to the author Olpinski and the oxidation method under adiabatic conditions have already been used to verify the tendency of coal to spontaneous combustion. Later the method of pulse calorimetry and the CPT (Crossing Point Temperature) method were used for the OKR coal. Experimentally the method according to the author Veselovskij was verified. The presented paper describes the objective methods, their technical performance and criteria of assessment of susceptibility of coal to spontaneous combustion.

Abstrakt

Samovznícení uhelné hmoty představuje značné riziko spojené s ohrožením zdraví pracovníků a důlního provozu, což je často spojeno s výpadkem těžby a s náklady na likvidaci endogenního požárů. Včasné rozpoznání samovznícení má velice důležitou roli v hlubinném dobývání uhelných slojí náchylných k samovznícení. Náchylnost uhlí k samovzněcovacímu procesu je považována za vlastnost uhelné hmoty, kterou lze stanovit laboratorní zkouškou. V OKR jsou již od sedmdesátých let minulého století používány pro ověřování náchylnosti uhlí k samovznícení metoda podle autora Olpinského a metoda oxidace za adiabatických podmínek. Později byla pro uhlí OKR ověřena metoda pulsní kalorimetrie a průsečíková metoda CPT (Crossing Point Temperature). Experimentálně byla ověřena metoda podle autora Veselovského. Předložený článek popisuje předmětné metody, jejich technické provedení a stupnice hodnocení náchylnosti uhlí k samovznícení

Key words: spontaneous combustion, spontaneous heating, susceptibility of coal to spontaneous heating, endogenous fire.

1 INTRODUCTION

An attention was paid in OKR to the question of endogenous fire especially in the seventies and eighties of the last century namely by the Scientific Research Coal Institute in Ostrava-Radvanice, today VVUÚ, a. s. At present three sites are in OKR dealing with the assessment of susceptibility of coal to spontaneous combustion. It concerns the above-mentioned site of VVUÚ, a. s. followed by the site of the University of Ostrava, Department of Chemistry and VSB-Technical University of Ostrava, the site of the Institute of Mining Engineering and Safety of the Faculty of Mining and Geology.

2 METHODS USED IN OKR

At VVUÚ, a. s. [1] the assessment of susceptibility of coal to spontaneous combustion has been performed continuously for more than 30 years. It concerns both a routine classification and research of spontaneous combustion process and its affection by various factors. Two methods are currently available at VVUÚ, a. s. - the method of oxygen sorption on adiabatic conditions (method of adiabatic oxidation) and the method according to the author Olpiński [2].

A further used method evaluating the coal mass susceptibility to spontaneous combustion is the method of pulse calorimetry. The method was verified in the Institute of Geonics of the Academy of Sciences of the

Czech Republic in Ostrava-Poruba in the eighties of the last century [3]. Analyses of coal samples by the method of pulse calorimetry are currently carried out at the Department of Chemistry of the University of Ostrava.

The last evaluating method of susceptibility of coal to spontaneous combustion in OKR is the CPT method. Since 1999 the method is available for determining susceptibility of coal to spontaneous combustion at the Institute of Mining Engineering and Safety of the VSB-Technical University in Ostrava [4]. At the same site the method of isothermal oxidation according to the author Veselovskij [5]was experimentally verified in the years 2003-2005.

2.1 Method of oxidation on adiabatic conditions

The method of oxidation on adiabatic conditions is based on an assessment of verified samples during a contact with an oxidation medium (clean oxygen, air etc.) on conditions approaching the conditions adiabatic, i.e. without any energy exchange with the environment under a sufficient supply of oxygen and minimum heat dissipation [1]. The method principle is widely used abroad and is considered as the most credible laboratory method namely by reason of simulation of real behaviour of spontaneous combustion in situ [3].

Under technical conditions of the apparatus being used at VVUÚ, a. s. (Fig. 1) a weighed sample of coal (250 g) the grain-size of which is below 2 mm is placed to a glass reactor immersed in an oil bath of an adiabatic calorimeter. Consequently the sample is temperated to 60 or 80 °C [6] and exposed to effect of clean oxygen, the flow rate of which is 20 $ml.min^{-1}$, or perhaps any other oxidation mixture, e.g. air, oxygen-nitrogen mixture. An average temperature rise resulting from coal oxidation is assessed At ($°C.hour^{-1}$). The higher the temperature gradient is, the higher is the inclination of the assessed sample to spontaneous combustion. The temperature of the oil bath is automatically balanced during the test to the temperature of the oxidized coal, therefore no heat dissipation developed by oxidation occurrs and depending on the released heat of oxidation a temperature rise of coal takes place [4].

For an initial temperature of 80 °C a black coal is divided according to an average temperature rise ($°C.hour^{-1}$) to the following four classes for 'clean oxygen' oxidation medium [4]. The listed temperature intervals are overlaid. It results from experience of the presented method operator that determining an appropriate class requires experience of a laboratory assistant based on the temperature dynamics of the test:

- Susceptibility to spontaneous combustion - low 0 to 8 ($°C.hour^{-1}$)
- Susceptibility to spontaneous combustion - medium 5 to 10 ($°C.hour^{-1}$)
- Susceptibility to spontaneous combustion - considerable 8 to 18 ($°C.hour^{-1}$)
- Susceptibility to spontaneous combustion - extraordinary Over 15 ($°C.hour^{-1}$)

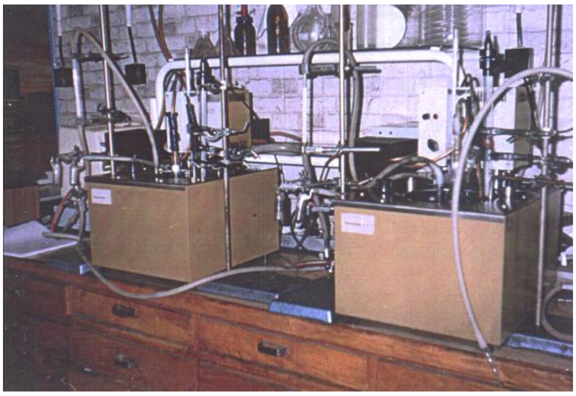

Fig. 1: Apparatus of the oxidation method on adiabatic conditions

2.2 Method according to Olpiński

The method assesses speed of the sample heating by oxidation under a constant temperature (212 or 235 °C) of the apparatus inner space. The constant temperature is reached through boil of quinoline (boiling-point 235 °C) for analyses of black coals, or ethyl ester of benzoic acid (boiling point 212 °C) for analyses of brown coals [3]. The apparatus (Fig. 2) consists of heating space with a boiling flask whose purpose is to heat the outer cover of the reaction zone and also serves to pre-heating the air passing through the reaction zone. A coal sample the grain-size of which is 0.06 to 0.075 mm, ash content less than 35% and weigh 2g is pressed to a briquette of a cylindrical shape of exactly given size, on one side open. Consequently the roller is placed on the top of a thermoelectric couple so that the hot junction is in a close contact with the solid bottom of the roller [4]. The pressed coal briquette (roller) is inserted into the reaction zone pre-heated to the temperature of 212 or 235 °C. The sample is exposed to airflow of volume flow rate of 100 $l.h^{-1}$. During the test the rise in temperature inside the sample is recorded in periodic time intervals. The method tracks the temperature gradient, which we assess as an index of spontaneous combustion SZ_a ($°C.min^{-1}$), i.e. ratio of legs of rectangular triangle whose hypotenuse is a tangent led to the curve of the record in a so-called adiabatic point, which matches to the temperature of 212 or 235 °C [6].

According to the SZ_a index value we divide coal into the following classes of susceptibility to spontaneous combustion (Tab. 1):

Tab. 1: Classes of coal susceptibility to spontaneous combustion according to Olpiński, [6].

Word assessment	**SZ_a ($°C.min^{-1}$)**
Susceptibility to spontaneous combustion - low	0 to 40
Susceptibility to spontaneous combustion -medium	40 to 80
Susceptibility to spontaneous combustion -considerable	80 to 180
Susceptibility to spontaneous combustion -extraordinary	Over 180

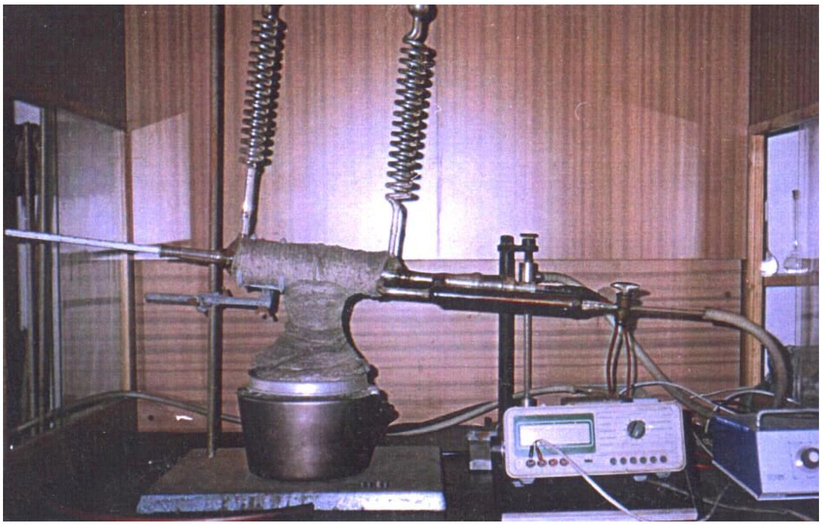

Fig. 2: Apparatus for determining of coal susceptibility to spontaneous combustion by Olpiński

2.3 Method of pulse calorimetry

The method principle consists in assessment of quantity of heat released from the weighed sample of coal oxidized in the calorimeter of the manufacturer SETARAM (Fig. 3). The verified coal sample is exposed to oxidation while contacting with a constant volume of oxygen [3]. The method enables measuring the released oxidizing heat q^{30} ($J.g^{-1}$). The oxidizing heat q^{30} represents the heat released by a chemical reaction of oxygen and coal for the period of 30 minutes. Preparation of the coal sample before starting to measure consists in grinding lump coal in the inert atmosphere [7] and sieving to a required fraction of 0.06-0.14 mm. Quantity of the released heat is determined via the SETARAM C 80 calorimeter.

According to the value of heat q^{30} the coal sample is included to one of the following classes of susceptibility to spontaneous combustion according to the Tab. 2 :

Tab. 2: Classes of coal susceptibility to spontaneous combustion according to the method of pulse calorimetry

Class of susceptibility to spontaneous combustion	q^{30} **(J.g^{-1})** **Black coal**	q^{30} **(J.g^{-1})** **Brown coal**
Low susceptibility to spontaneous combustion	< 0,35	< 3,5
Increased susceptibility to spontaneous combustion	0.35 to 0.85	3.5 to 7.5
High susceptibility to spontaneous combustion	> 0,85	> 7,5

Fig. 3: SETARAM C 80 calorimeter at the University of Ostrava

2.4 CPT (Crossing Point Temperature) method

The issues of spontaneous combustion of coal a special attention was paid at the Institute of Mining Engineering and Safety, Faculty of Mining and Geology of the VSB-Technical University in Ostrava in the years 1996-1997, when the Laboratory of Spontaneous Combustion of Substances at the Institute was established. A ground of the Laboratory at that time was the apparatus of adiabatic thermostat. The Department of Electrotechnics of the Faculty of Electronics of VSB-Technical University of Ostrava participated in its establishment. In the year 1999 the thermostat mode was adjusted for applying the CPT method [4].

The ground of the measuring apparatus of the Laboratory of Spontaneous Combustion of Substances of the VSB-Technical University in Ostrava is the thermostat of U16 type (Fig. 4) with a heating coil of 1.72 kW and a crankcase oil pan of volume of 16 l. The reactor resembles a glass washing bottle of volume of 0.5 l with a filter glass at the bottom. The reactor is equipped with a preheating glass coil serving to thermal drawback of the incoming oxidizing medium. Parts of the apparatus are two thermoelectric couples of K type, an integrated AD595AQ amplifier, gravity-operated and electric flow meters and pressure bottles with technical gases. The control of the measuring apparatus is ensured by PC via A/D converter card, KUAN triac converter and control relays. A control PC program has been created through the Control Panel 2.2 application. Since 1999 also gas line has become a part of the apparatus (Fig. 5) for analysing the output gaseous products. For the CPT method the non-linear temperature rise with a value of the temperature gradient in a range of 0.2 - 4.0 °C.min^{-1} with the initial temperature rise of 4.0 °C.min^{-1} and consequently a gradual temperature rise up to a value of 0.2 °Cmin^{-1} at the end of measurements upon a constant time period of 4 hours of the analysis in a temperature range of 25-200°C [4]. The CPT value of coal is a parameter, which depends on the measuring apparatus configuration and further affecting factors [8]. It expresses a temperature value of crossing point of the temperature rise of the oil bath and the temperature of the coal sample being verified during the test.

The method compares potential of spontaneous combustion of coal of various types provided that specified experimental conditions are met. The author Banerjee calls your attention as well to an effect of water content in highly wet types of coal which might considerably distort the test results. These analysis factors shift the CPT value upwards [8].

Fig. 4: U16 thermostat together with a reactor

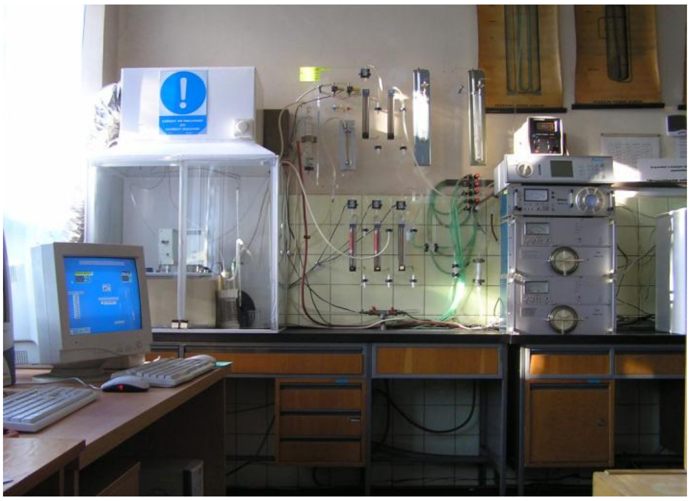

Fig. 5: Measuring apparatus of the CPT method together with a gas line

3 INDEX OF SUSCEPTIBILITY "INS"

By reason of different evaluation scales of individual assessment methods of coal susceptibility to spontaneous combustion (method according to Olpiński, method of pulse calorimetry, CPT method and method of adiabatic oxidation), a complex parameter of susceptibility to spontaneous combustion has been determined associating results of all methods [4]. To each of methods a re-assessed, standardized, value meaning was assigned and the resulting parameter was expressed in one assessing parameter - "INS" index (Index of Susceptibility to Spontaneous Combustion). For the parameter a standardized index has been selected that assumes values from 0 to 1 and a three-stage classification scale of susceptibility has been devised - "susceptibility low, medium and high". Interface between stages has been selected linearly (0.0 - 0.333 - 0.666 - 1.0). The selected range of parameter values of partial methods for the interval 0.0 - 1.0:

- Method according to Olpiński: SZa = 0 – 75 °C/min
- Method of adiabatic oxidation: At = 0 – 6 °C/h
- Method of pulse calorimetry: q^{30} = 0 – 1,2 J/g
- CPT method: CPT = 182 – 161 °C

The range of the partial methods has been adjusted to a standardized value expression in the interval 0.0 - 1.0 by means of the following calculations (measured value divided by the interval value):

- Method according to Olpiński: $I_O = SZa/75$
- Method of adiabatic oxidation: $I_A = i_A/6$
- Method of pulse calorimetry: $I_K = q^{30}/1,2$
- CPT method: $I_{CPT} = (182 - t_{CPT})/21$

The resulting „INS“ index (1) is expressed by arithmetic mean of four above mentioned indices:

$$INS = (I_O + I_A + I_K + I_{CPT})/4 \qquad (1)$$

Such used way of assessment integrated results of the used methods.

Consequently a software application “Index of susceptibility to spontaneous combustion of the OKR coal” has been created [4] in the Mutlimedia Builder 4.8 software environment that contained the computing algorithm of “INS”. Measured values of the partial methods serves as input data, the output is represented by “degree of susceptibility” according to the “INS” index.

4 EXPERIMENTAL ASSESSMENT OF VESELOVSKIJ METHOD

An experimentally verified method of determining susceptibility to spontaneous combustion of coal is the method of isothermal sorption of oxygen. The ground of the method lies in the Russian “U“ index [9]and “Flask Test” of the American Mine Safety and Health Administration [10]. The author of the Russian “U“ index is V. S. Veselovskij. The method of the “U“ index consists in closing a weighed sample of coal (40g), fraction 1 - 3.175 mm to a flask. After the elapse of 24 hours the atmosphere inside the flask is analyzed namely for contents of CH_4, O_2, CO_2 (Fig. 6). Decrease of oxygen in the flask is determined via a relation (2). The relation is intentionally provided in the original author’s version [9]:

$$U = -\frac{V(B-P)}{W.t.760}\ln\frac{(1-CO)Ca}{CO(1-Ca)}, \qquad (2)$$

where:

V - air volume in closed flask, [ml],

P - pressure of saturated vapour at 25 °C [23.8 mm Hg],

B - barometric pressure, [mm Hg],

W - weighed portion of coal, [g],

t - time of adsorption, [hour],

CO - oxygen concentration in the air, [%]

Ca - oxygen concentration in the air of flask after the elapse of time t, [%]

760 - barometric pressure of the air on normal conditions, [torr].

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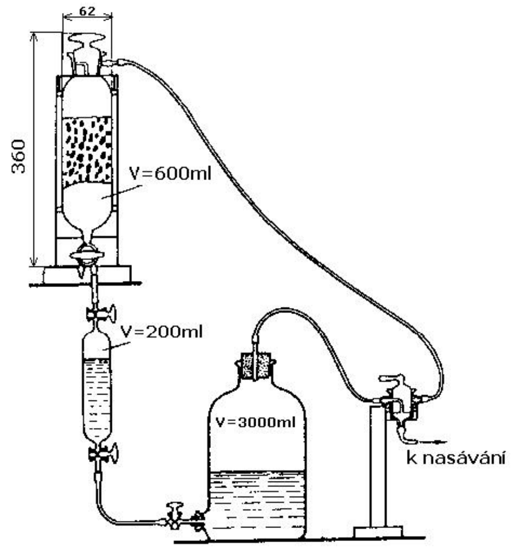

Fig. 6: Apparatus schema of the Russian "U" index method [9].

The "Flask Test" assesses a coal sample of weight of 50g placed in six Erlenmayer flasks provided with pressure sensors for specification of pressure drop after 7 days [10], (Fig. 7). As a criterion of susceptibility to spontaneous combustion of coal the value of pressure drop by oxidation in closed flasks was considered. At the end of the test as well composition of the atmosphere inside the Erlenmayer flasks was studied especially concerning quantities of O_2, CO, CO_2, CH_4 and C_2H_6. Based on the analysis of the atmosphere inside the flasks the adsorbed O_2 quantity and CO index were specified (3).

$$COindex = \frac{CO}{O_2}, \qquad (3)$$

where:

CO - volume quantity of CO in the Erlenmayer flask [0.0001%],

O_2 - adsorbed oxygen quantity in volume percentage

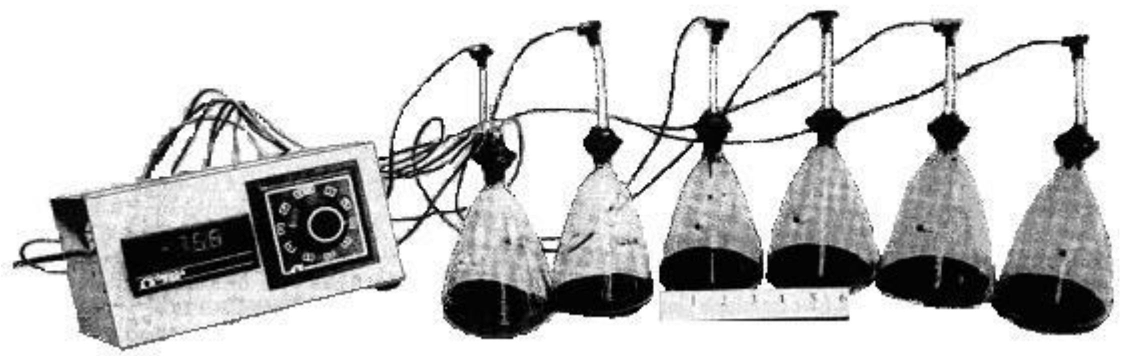

Fig. 7: "Flask Test" apparatus of the American Mine Safety and Health Administration [10].

The principle of the above mentioned isothermal oxygen sorption was experimentally verified at the Institute of Mining Engineering and Safety, VSB-Technical University in Ostrava [11]. Weighed samples of coal (50g) were placed in the Erlenmayer flasks for the period of 7 days (Fig. 8). As opposed to the Russian "U" index and American "Flask Test" only the pressure drop in closed flasks was tracked, not the composition of the atmosphere inside the flasks. As assessment parameter of susceptibility to spontaneous combustion of coal the area was selected over a curve of the pressure drop in the closed flasks denoted as a symbol "S" :

$$S = \sum_{0}^{t}(p_0 - p_t)\Delta t \,, \qquad (4)$$

where:

S - area,

P_0 - initial pressure,

p_t - pressure in time t,

Δt - time interval [3 min.].

The apparatus consisted of five Erlenmayer flasks (0.5l) fitted with pressure sensors of absolute pressure and one sensor of ambient temperature (Fig. 8). Sensing by the measuring apparatus was ensured via PC with a A/D converter card. The control software application has been created in the Control Web 2000 program.

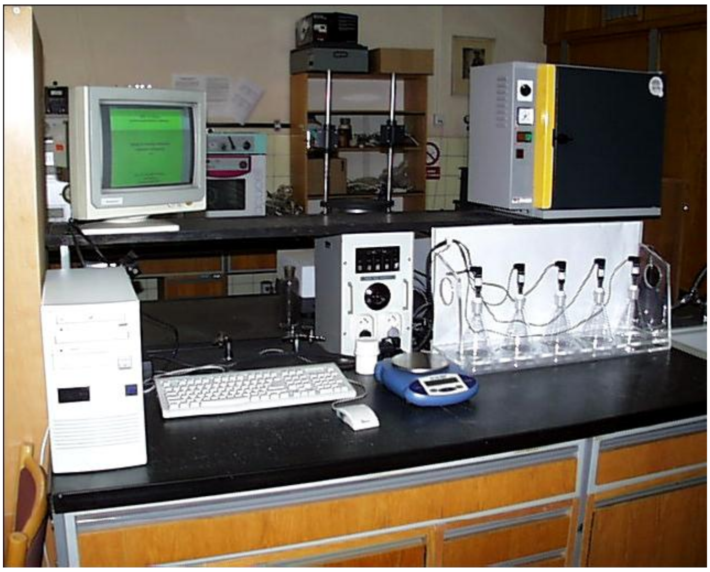

Fig. 8: Apparatus of isothermal sorption of oxygen at the VSB-Technical University of Ostrava

5 CONCLUSIONS

The above mentioned sites and their assessment methods of susceptibility to spontaneous combustion of coal do not serve only to routine assessment of OKR coal samples. An important task is fulfilled also by the sites in deepening knowledge of problems of spontaneous combustion of coal mass. The problems of spontaneous combustion of coal mass has not been so far completely explained in detail.

The author of the presented paper currently deals with an experimental assessment of the modified adiabatic method, whose variant is used as standard at the research mining institute INSEMEX in Petrosan [12]. A major advantage of the objective method is acceptable time consumption, i.e. the test duration of 20 minutes. Here a convenient solution can be found in term of small time consumption and accuracy of assessment of coal susceptibility to spontaneous combustion.

Assessment of degree of coal susceptibility to spontaneous combustion and its consequent classification is performed for the purpose of determining a risk of spontaneous combustion of coal and subsequent selection of preventive measures.

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RESUMÉ

K nejzávažnějším rizikům hlubinných uhelných dolů patří endogenní požáry. Proces samovzněcování uhlí představuje aktuální hrozbu pro důlní pracovníky v podobě výskytu oxidu uhelnatého a zápalné teploty metanu v důlních dílech. Jednou z okolností napomáhající zvyšování účinnosti protizáparové prevence je znalost náchylnosti uhlí k samovznícení v dané lokalitě. Náchylnost uhlí k samovznícení je fyzikálně-chemická vlastnost uhlí, kterou lze stanovit laboratorní zkouškou. Existuje řada laboratorních metod ověřujících náchylnost uhlí k samovznícení.

V OKR jsou v současné době tři pracoviště zabývající se touto problematikou. Jedná se o pracoviště VVUÚ, a. s., Ostravské univerzity, katedry chemie a VŠB-TU Ostrava, institut hornického inženýrství a bezpečnosti. Uvedená pracoviště ověřují náchylnost uhlí k samovznícení následujícími metodami: metoda oxidace za adiabatických podmínek, podle Olpinského (VVUÚ, a. s.), pulzní kalorimetrie (Ostravská univerzita) a CPT (VŠB-TU Ostrava). Na pracovišti institutu hornického inženýrství a bezpečnosti VŠB-TU Ostrava, laboratoři samovznícení látek, byla dále experimentálně ověřena metoda izotermické oxidace podle autora Veselovského a připravuje se zde v nejbližší budoucnosti ověření modifikované metody CPT podle autora Totha.