ASSESSMENT OF INDICATOR GASES OF SPONTANEOUS COMBUSTION IN UNDERGROUND MINES IN THE CZECH REPUBLIC

SLEDOVÁNÍ INDIKAČNÍCH PLYNŮ SAMOVZNÍCENÍ V HLUBINNÝCH DOLECH ČESKÉ REPUBLIKY

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Abstract

Research and applications of findings in the area of early indication of spontaneous combustion of coal using indicator gases started in the Czech Republic in the seventies to eighties of the last century. A significant progress occurred in the second half of the eighties, when methods of assessment of coal self-heating temperature were published in the Czech Republic (CR), e.g. in [1]. Consequently the objective findings of the research were projected in the year 1990 to generally binding legislation of the State Mining Authority of CR, imposing to track and assess indicator gases [2]. The matter of fact required to establish in the Ostrava-Karvina Coalfield (OKR) operational chromatograph laboratories covering requirements of practice. Further research was focused on improvement of assessment of self-heating temperature using indicator gases. The presented paper describes briefly the previous work experience and some findings of the research from the area of the tracking of indicator gases of spontaneous combustion in underground coal mines in CR.

Abstrakt

Výzkum a aplikace poznatků v oblasti včasné indikace samovznícení uhlí pomoci indikačních plynů mají v České republice své prvopočátky v sedmdesátých až osmdesátých létech minulého století. Významný posun nastal v druhé polovině osmdesátých let, kdy byly v České republice (ČR) publikovány metody pro odhad teploty samovznícení uhlí, např. [1]. Následně se předmětné poznatky výzkumu promítly v roce 1990 do obecně závazné legislativy státní báňské správy ČR, ukládající sledovat a vyhodnocovat výzkumem ověřené indikační plyny [2]. Tato skutečnost si vyžádala v Ostravsko-karvinském revíru založení provozních chromatografických laboratoří pokrývajících potřeby praxe. Další výzkum byl zaměřen na zdokonalením odhadu teploty samovznícení pomoci indikačních plynů. Předložený článek stručně popisuje dosavadní praxi a některé poznatky výzkumu při využívání indikačních plynů v hlubinných uhelných dolech ČR.

Key words: spontaneous combustion, tepmperature of self heating, chromatograph anylysis, higher hydrocarbons, carbon monoxide, carbon dioxide.

1 INTRODUCTION

Some of the first findings on gases being liberated from coal during spontaneous combustion come from the Doncaster Mine Safety Laboratory from the first half of the twentieth century in the form of Graham's numbers [3]. The Graham's numbers express the ratio between increase in carbon dioxide and carbon monoxide concentrations and oxygen drop. Regarding the considerable quantity of nitrogen used in OKR (Ostrava-Karvina Coal Field) during heating prevention the Graham's criterion is no longer predicative, however it is utilized till now e.g. in the Polish part of the Upper-Silesian Coal Basin namely thanks to generally binding regulation [4]. A meaningful progress in the area of indicator gases occurred in late fifties of the last century, when Japanese author Kittagowam presented at the conference of mine safety research institutes in Pittsburgh the research results, in which he proved that in the mine atmosphere further gases occur relating to spontaneous combustion of coal, especially ethylene [5]. So the worldwide research has been initiated oriented to indicator gases that were designated as higher hydrocarbons. In the given trend in the subsequent sixties and seventies the research was realized, e.g. in Poland [6], Great Britain, tracking up to twenty gaseous hydrocarbons [7,8], Ukraina [9], Canada [10] and later in Germany [11].

In the Czech Republic the objective research was initiated first in the CSAS Mining Research Institute in Prague [12] and in Ostrava [22]. The research continued in the Science-Research Coal Institute in Ostrava-Radvanice [13] and also in cooperation of the Science-Research Coal Institute in Ostrava-Radvanice and Central Mines Rescue Station in Ostrava-Radvanice. One of the results of the Central Mines Rescue Station was "Temporary method for evaluation of chromatographic determination of hydrocarbons" [14] and later the methods for "Evaluation of self-ignition process of black coals in Saddle seams in OKR using gas chromatography " [1], today known under the name "Column diagram of the Central Mines Rescue Station in Ostrava**".** In the Czech Republic the issues of application of indicator gases are actual especially in OKR, where about twenty cases of a limit occurrence of carbon monoxide per year is reported (30 ppm or 10 l.min $^{-1}$). The coalfield in question is located in the North-East part of CR, it takes up one fifth of the Upper-Silesian Coal Basin and in the year 2006 there was extracted 14.28 million tons of black coal from the depth of 800-1000 m below the surface.

The listed results of the research made possible in the year 1990 the State Mining Authority of CR to be able to impose a number of binding duties for mines of OKR in relation to occurrences of indicator gases of spontaneous combustion in the mine atmosphere.

2 INDICATOR GASES TRACKED IN THE OKR MINES

Based on up to now experience in mines in CR, indicator gases of spontaneous combustion can be divided into two groups, majority (basic) and minority (additional) gases. The division results in principle from implemented routine of sampling mine atmosphere. Samples of the mine atmosphere are taken in CR mines according to the Czech Technical Standard [15], i.e. sampling mine atmosphere through the use of wet samples taken by glass sample tubes filled with sealing liquid and dry sampling using vacuum ejectors. For the OKR mines sampling mine atmospheres for the following gases analyses is binding:

- Majority gases (wet sampling): CO_2, CO, O_2, CH_4,
- Minority gases (dry sampling): H_2, C_2H_6, C_3H_8, nC_4H_{10}, iC_4H_{10}, C_2H_4, C_3H_6, C_2H_2.

Desorption intensity of the objective indicator gases from coal mass was tracked under the conditions in OKR especially within the classification of seams prone to spontaneous combustion, e.g. [16,17]. Within the objective classification 64 coal samples in total were inspected and classified till the year 2002. As a result of compilation of lab-verified gaseous images of the indicator gases of the coal samples is the following diagram – Fig. 1.

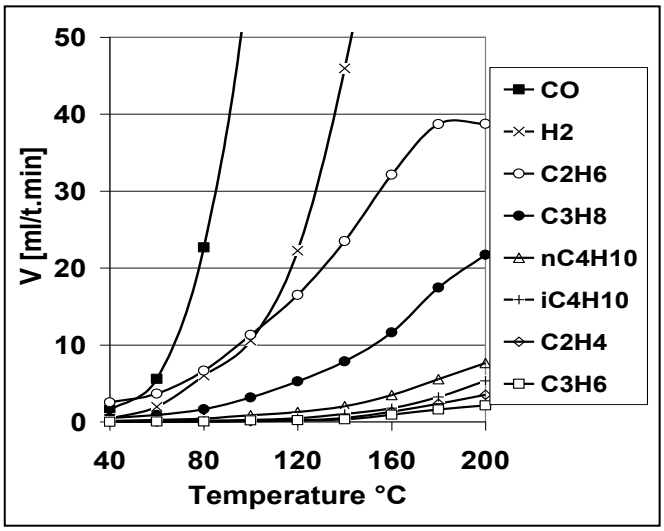

Fig. 1 Average formation of products of thermal oxidation of OKR coal samples, [19].

3 LEGISLATION

Heating prevention is legalized in generally binding legislation of CR, especially in Ordinance of the Czech Mining Office No. 22/1989 Sb. (Sb.-Coll.) [18] and in Binding Decision of the District Mining Office in Ostrava No. 10/1990, to ensure uniform fulfillment of requirements of Ordinance No. 22/1989 Sb. in the OKR mines. Obligations resulting from the mentioned regulations include:

- Article 109a, Section 3b, 22/1989 Sb. - permanent inspection of CO concentrations using continual analyzers must be performed in coal mines in seams prone to spontaneous combustion in fresh intake of a separate air compartment and in air return of a coal face,
- Article 110, Section 1, 22/1989 Sb. – samples of the mine atmosphere and their analyses of CH_4, CO_2, CO, O_2 must be performed in a gassy mine at least once a month in air mine workings nearby faces and stopes, in ventilated mine workings driven separately,
- Article 109, Section 4, 22/1989 Sb. - occurrence of CO and CO_2 in the mine atmosphere must be find out in places and intervals determined by the organization, however always where suspicion of their occurrence appears,
- Article 30, Decision No. 10/1990 – if CO is found out, it is necessary to find promptly its reason and verify its concentration in particular by analyses of air samples,
- Article 187, Section 6, 22/1989 Sb. - in order to ensure promptly detection of spontaneous combustion process the organization must evaluate formation of CO,
- Article 39, Section 3, Decision No. 10/1990 – for gas-chromatographic analysis samples of masses of air must be taken in air current, where the occurrence of CO over 0.001 % was found for the period of 24 hours or when volume formation of CO rises over 10 l min^{-1}; at coal faces then in through-circulating current:
    - Once a week – in case that CO concentration or CO volume formation does not raise any longer,
    - Twice a week - in cases when the volume formation of CO and higher hydrocarbons permanently increases,
- Article 39, Section 3, Decision No. 10/1990 – when finding out C_2H_4, C_3H_6 or in case of further increase of CO volume formation and higher hydrocarbons concentrations the air samples must be taken repeatedly. Frequency of inspections and further air sampling even in non-working days must be determined in writing and with respect to development of the situation by chief of average settlement,
- Article 39, Section 6, Decision No. 10/1990 – when finding out C_2H_4 or C_3H_6 repeatedly or in case of permanent increase of CO volume formation, when it is not possible to damp down the centre of spontaneous combustion by direct intervention including cases, when the centre is not accessible for such intervention, the danger area must be closed using explosion-proof tight dams as fast as possible in all cases, when
    - a risk is imminent of inflammable gases accumulation in the area of location of the centre of spontaneous combustion,
    - it is not possible to damp down the centre of spontaneous combustion so that it does not spread and no explosion risk occurs,
- regardless of the condition of spontaneous combustion,
- Article 39, Section 7, Decision No. 10/1990 – provided that by the analysis presence of C_2H_2 is finding out, it is necessary to close promptly the threatened area.

4 TECHNICAL EQUIPMENT

Samples of the mine atmosphere in OKR are taken into glass sample tubes of volume of 1 litre (wet sampling for analysis of majority gases) and of volume of 0,5 litre (dry sampling for chromatographic gas analysis). The glass sample tubes are provided with rubber hoses and cock pinches. It is necessary to deliver the taken sample to the laboratory no later than within 6 hours after sampling [15]. The majority indicator gases are analyzed in gas chemical laboratories being located above ground at every mine. Analyses of CO, CO_2 are ensured by infra-red analyzers (UNOR, MAIHAK MULTOR), oxygen analyse are ensured by paramagnetic analyzers (SERVOMEX). Methane is not considered as indicator gas of spontaneous combustion under conditions of gassy OKR mines.

After acceptance of binding decision [2] in the year 1990, imposing to track minority indicator gases (H_2, C_2H_6, C_3H_8, nC_4H_{10}, iC_4H_{10}, C_2H_4, C_3H_6, C_2H_2), operation chromatograph laboratories were established in OKR at two mine enterprises, at the Darkov Mine in Karvina and Lazy Mine in Orlova. At that time a chromatography laboratory was in operation at the Central Mines Rescue Station in Ostrava-Radvanice, today see Fig. 3. In Fig. 2 distribution of gaseous chemical and chromatography laboratories of the OKR mines is illustrated.

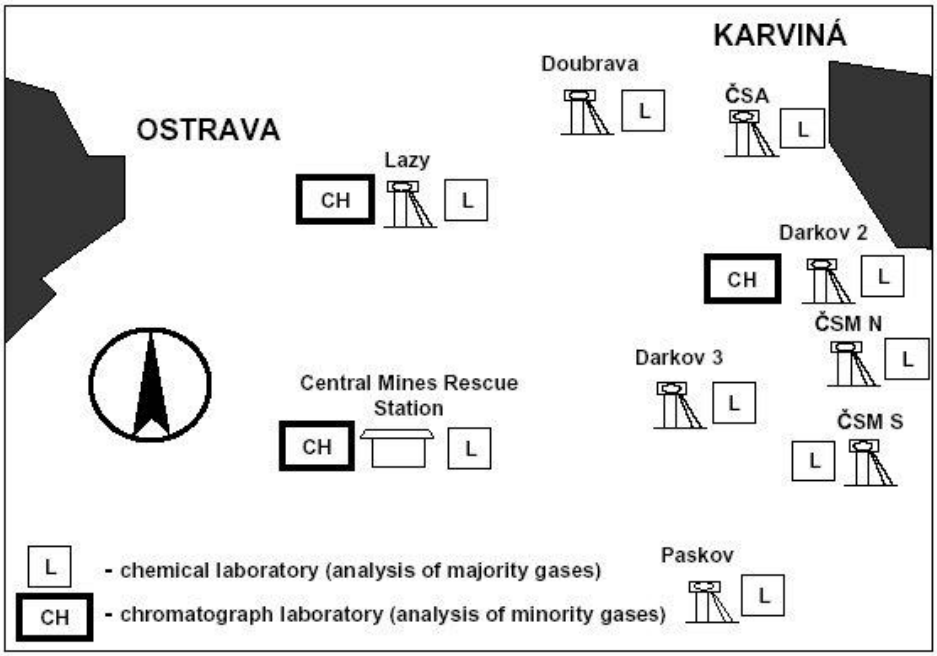

Fig. 2 Distribution of gaseous chemical and chromatography laboratories of the OKR mines

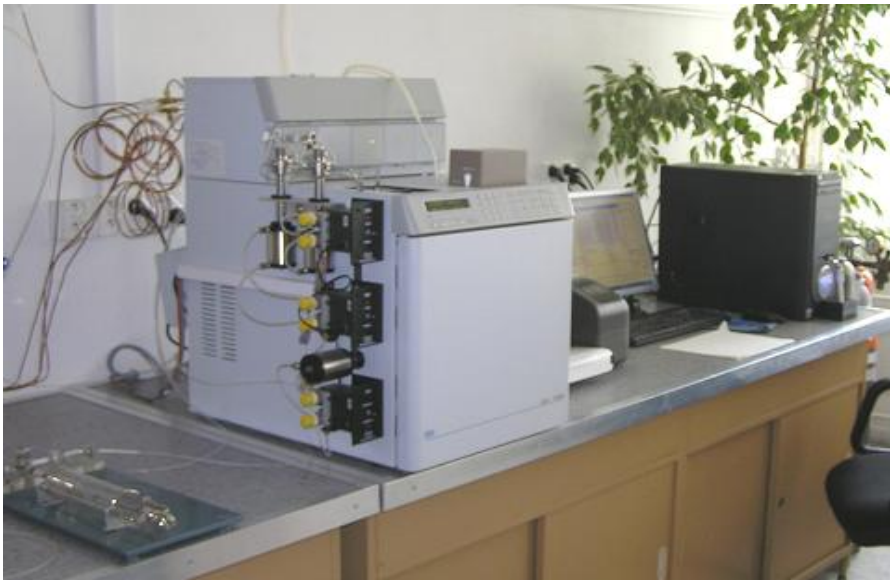

Fig. 3 DANI GC 1000 DPH Chromatograph of the chromatography laboratory of Central Mines Rescue Station in Ostrava

5 CONCLUSIONS

Rules which regulate tracking the indicator gases of spontaneous combustion especially in OKR can be specified in three areas:

- Generally binding regulations (Ordinance of CMO No. 22/1989 Sb., Decision No. 10/1990 of OBÚ Ostrava, [18], [21]),
- Internal directive (spontaneous heating of coal protection directive),
- Recommended methods (column diagram of the Central Mines Rescue Station in Ostrava [1]).

The generally binding regulations impose to track CO continuously in mines in CR and in case of its occurrence to take appropriate measures. Consequently for the OKR mines it is imposed to track occurrence of minority indicator gases provided that CO is measured for the period of 24 hours in concentration of 10 ppm or its formation exceeds 10 l min^{-1}. The tracked occurrences of the indicator gases aspire then to precautions especially to closing the threatened areas when finding out repeatedly C_2H_4 or C_3H_6 or in case of permanent increase of volume formation of CO and occurrence of C_2H_2. A criterion of an occurrence of minority indicator gases is sensitivity of gaseous chromatography of the OKR laboratories that can capture indicator gases from 0.1 ppm. The internal directives for heating protection of the OKR mine plants impose especially rating of risk related occurrences of spontaneous combustion before commissioning of mine workplace and measures for heating protection for both preparatory and operational stages.

The generally binding regulations and internal directives do not deal with estimation of temperature of the centre of spontaneous combustion. This area is a subject matter of methods, e.g. [1], [14], [20]. The temperature estimation is important especially in the area of critical temperature of spontaneous combustion, which ranges from 60 to 100 °C as for the OKR coal and in the area of achievement of coal igniting point, after whose exceeding the initiation temperature of methane-air mixture can be soon achieved in the centre of spontaneous combustion.

In OKR for temperature estimation of the centre of spontaneous combustion both can be used today: estimation according to initial occurrences of indicator gases, e.g. Fig.1 and according to their absolute concentrations [1], [14], and temperature estimation according to the column diagram of the Central Mines Rescue Station in Ostrava that is determined for rating of gases samples taken in through-circulating current [1], temperature estimation according to laboratory verified gaseous images of indicator gases obtained by the thermal oxidation method, e.g. [20], and also by tracking the binary indicator CO_2 /CO, whose behaviour was standardized based on numerous laboratory analyses of the thermal oxidation of coal samples for conditions of OKR. Three from the presented methods are a subject matter of a computer program [21]. However, it is necessary to underline that the temperature estimation through the use of the presented methods is not exact; it concerns estimation of the temperature only, not its determination.

Considering the dynamics character of spontaneous combustion process it is important to determine the critical temperature of a given centre of spontaneous combustion, because after exceeding the critical temperature its dynamic increase occurs and increase of demands on measures for heating protection. At the same time success of repressive interventions decreases as a rule and real risk appears of achievement of the initiation temperature of methane-air mixture in the centre of spontaneous combustion.

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RESUMÉ

V dolech České republiky je obecně závaznými předpisy uloženo ve vztahu k včasnému rozpoznání samovznícení uhlí kontinuálně sledovat výskyt CO a v dolech OKR pravidelně sledovat výskyt H_2, C_2H_6, C_3H_8, nC_4H_{10}, iC_4H_{10}, C_2H_4, C_3H_6, C_2H_2 v případech kdy CO je registrován po dobu 24 hodin v koncentraci 10 ppm, nebo jeho vývin je nad 10 $l.min^{-1}$. Obecně závazné požadavky byly přijaty státní báňskou správou na základě poznatků výzkumu z osmdesátých let minulého století a jsou v dolech OKR plněny od roku 1990. K zabezpečení

předmětných požadavků jsou v OKR provozovány tři chromatografické plynové laboratoře, dvě na důlních podnicích a jedna na HBZS v Ostravě-Radvanicích. Předmětné laboratoře analyzovaly za dobu své existence již desetitisíce vzorků důlního ovzduší.

Obecně závazné požadavky jsou v oblasti výskytu CO a předmětných nenasycených uhlovodíků zaměřeny na bezpečnostní opatření, směřující k uzavření ohrožených důlních děl v případech stálého nárůstu CO a v případech opakovaného výskytu C_2H_4, C_3H_6. V případě výskytu C_2H_2 je uloženo neprodleně přistoupit k uzavření ohrožených prostor. Kritériem výskytu C_2H_4, C_3H_6, C_2H_2 je jejich zjištěná koncentrace 0,1 ppm (kvalita chromatografické analýzy).

Určením teploty ohniska samovznícení se obecně závazná pravidla nezabývají. Teplotou ohniska samovznícení se zabývají doporučené metody, pomocí kterých lze teplotu ohniska odhadovat. Patří zde odhad teploty podle prvotního výskytu indikačního plynu, podle litrového vývinu ve vzorcích plynů odebraných v průchodním větrním proudu, podle standardizovaného binárního ukazatele CO_2 /CO a podle srovnávání poměrů koncentrací indikačních plynů důlního ovzduší s laboratorně ověřenými plynovými obrazy uhelných vzorků získaných metodou tepelné oxidace. K tomuto účelu lze dnes v OKR využít výpočetní program, např. [21]. Přesnost stanovení teploty ohniska samovznícení je orientační, jedná se o odhad teploty, nikoliv o určení teploty.

Vzhledem k charakteru dynamiky samovzněcovacího procesu je významné určení kritické teploty daného ohniska samovznícení, neboť po překročení kritické teploty dochází k jejímu dynamickému nárůstu a ke zvýšení náročnosti na protizáparová opatření. Zároveň se zpravidla snižuje úspěšnost represivních zásahů a vzniká reálné riziko dosažení iniciační teploty iniciace metanovzdušné směsi v ohnisku samovznícení.