OVERVIEW OF RESEARCH AND USE OF INDICATOR GASES OF COAL SPONTANEOUS COMBUSTION IN CHINA

PŘEHLED VÝZKUMU A VYUŽITÍ INDIKAČNÍCH PLYNŮ SAMOVZNÍCENÍ UHLÍ V ČÍNĚ

Xiyang FENG [1], Alois ADAMUS [2]

[1]*Institute of Safety Technology Management, Faculty of Prospecting and Mining Engineering, Yunnan Land and Resources Vocational College, 2. Jingniu Road, Yunnan, China,*
Tel.: +420, 608,882,539
e-mail 68775351@QQ.com

[2] *Prof. Ing. PhD., Institute of Mining Engineering and Safety, Faculty of Mining and Geology, VŠB – Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava – Poruba, Czech Republic,*
Tel.: (+420) 59 732 3358
e-mail alois.adamus@vsb.cz

Abstract

The beginnings of research and use of results in the area of indicator gas application for early detection of spontaneous combustion of coal in China comes from the sixties of the last century. The significant development occurred in the nineties, when the program "Characteristics of the adsorption of coal oxygen and its application in the prevention of mine fires" had been completed. The paper briefly describes an overview of the historical development, achievements, experimental methods, laboratory equipment, legislation, and the outlook for the use of indicator gases of coal spontaneous combustion in China.

Abstrakt

Počátky výzkum a využití výsledků v oblasti aplikace indikačních plynů pro včasnou detekci samovznícení uhlí pochází v Čině z 60tých let minulého století. Ke značnému rozvoji došlo v devadesátých létech, kdy byl dokončen program „Charakteristika adsorpce kyslíku uhlí a její aplikace v prevenci důlních požárů". Předložený článek stručně popisuje přehled historického vývoje, dosažené výsledky, experimentální metody, laboratorní vybavení, legislativu a výhled vývoje využití indikačních plynů samovznícení uhlí v Číně.

Key words: coal, spontaneous combustion, indicator gas.

1 INTRODUCTION

The findings related to the application of indicator gases for early detection of coal spontaneous combustion globally come from the first half of the 20th century. It was primarily Graham [1,2], whose indicators have used in many of the world's coalfields up to now, and subsequently Kitagawa [3], the first author dealing with released gaseous hydrocarbons in spontaneous combustion. In Chinese coal mines, only CO was monitored till the end of the 50s in the given context. Mines, which mine coal with a content of pyrite and have considerable difficulties with the presence of endogenous fires, confirmed the existing practices of spontaneous combustion indications as insufficient at the time. For this reason, in the sixties, a number of Chinese mines started to investigate spontaneous combustion indicator gases with a focus on local mining conditions.

2 EXPERIENCE IN USING INDICATOR GASES IN CHINA

In 1966, a research team at the Yuanbaoshan Mine in the Liaoning Province was formed whose aim was to examine relations of development of spontaneous combustion temperatures and gas compositions in obtained gas samples, focusing mainly on the presence of CO and related factors (litre emission, decreased oxygen, increased CO_2), [4]. The experiments confirmed that the concentration of CO increases with temperature in the centre of spontaneous combustion with a simultaneous decrease in oxygen and an increase in CO_2. Two prediction methods of spontaneous combustion were set – the method of an increase in CO concentration and the method for tracking CO litre emission. One of the results of the research was the concentration limit values listed in Tab. 1. The threshold CO litre emission value of spontaneous combustion was set to 5.9 l/min.

Tab. 1 Limit values of the initial state of spontaneous combustion for the Yuanbaoshan Mine, [4]

	+CO	$-\Delta O_2$	$+CO_2$
limit for normal conditions	<0.0020%	<0.5%	<0.15%
characteristics	main indicator	subsidiary indicator	subsidiary indicator

The China Coal Research Institute (CCRI), made up a research team in cooperation with the Gusan Mine in 1974, which followed the findings learned at the Yuanbaoshan Mine, [5]. The results were the indicators – H1 (litre emission of CO) and H2 (Graham's interpretation of indicators), which were verified in 36 cases and evaluated as satisfactory, see Tab. 2.

$$H_1 = CO \times Q \qquad (1)$$

$$H_2 = \frac{CO \times Q}{\Delta O_2 \times Q} \qquad (2)$$

where Q – a volume flow rate of a return airway of an active face, [m^3/min],

CO – a concentration, [%],

ΔO_2 – a decrease in oxygen, [%].

Tab. 2 Indicators H1, H2 monitored at the Gushan Mine according [5]

	current conditions	prediction	fire
H1(m^3/min)	<0.0049	0.0049-0.0059	>0.0059
H2 (-)	<1.0	1.0-1.8	>1.8

In the eighties of the last century, Graham indicators had been tracked by the authors Zhong Weiren and Li Fengze at the Laohutai Mine in Fushung for many years [6]. Later, the authors of [7] tracked them as well. The partial results are shown in Tab. 3:

Tab.3 Results from monitoring the Graham indicators at the Laohutai Mine, [6]

state of spontaneous combustion	G ($CO/\Delta O_2$)
common condition	0
phase of low-temperature oxidation	0-0.45
phase of high-temperature oxidation	0.46-4
phase of starting burning	4.1-9
fire	>9

Gaseous hydrocarbons were first used in China as indicator gases of spontaneous combustion in 1983 at the Chaili Mine, in particular in more than one hundred successful cases. According to the authors of [8], their applications were associated with the following shortcomings – ethylene was detected at coal temperatures of 110-130 °C, which was not considered sufficiently early indication, other unsaturated hydrocarbons like propylene, butylene and other gases occurred in low concentration, easily susceptible by the dilution through the volume flow of ventilation. In order to extend the existing knowledge, the research team from the Chaili Mine ensured taking 18 coal samples from Guizhou, Henan, Hebei, Anhui and other provinces which underwent further testing [8]. The experiments confirmed the relationship between the dimensionless indicator C2H6/C2H4 and the temperature of coal. The indicator value decreased with an increase in the temperature of coal, see Tab. 4. The given values of the indicators were used successfully in May 1986.

Tab. 4 The indicator value of C_2H_6, C_2H_6/C_2H_4 depending on the temperature according to [8]

indicator	value /-/	temperature	Condition
C_2H_4	detected	110-130°C	early detection
C_2H_6/C_2H_4	2-3	140-190°C	preparation of repression
C_2H_6/C_2H_4	≤1	>200°C	emergency condition – fire repression

In 1988, the Mining Institute of Liuzhi investigated the dependence of gaseous hydrocarbons C_2H_6, C_3H_8, C_4H_{10} and their dimensionless indicators C_4H_{10}/CH_4, C_3H_8/C_2H_6 on an increase in temperature. The indicator C_3H_8/C_2H_6 was finally chosen as a suitable indicator for early detection of spontaneous combustion of coal for the actual mining conditions, [9]. This information was also published by the author of [7], Tab. 5.

Tab. 5 The indicator C_3H_8/C_2H_6 as an indicator of spontaneous combustion prevention for the Liuzhi Mine, [7]

indicator	common condition	hazardous condition	state of spontaneous combustion
C_3H_8/C_2H_6	0.02-0.06	0.1-0.12	0.15-0.18

The above research brought numerous data and objective results only for specific mines. The results were burdened by certain limits and bias. In order to achieve the standards applicable nationally, China elaborated the research of coal spontaneous combustion into the “Sixth”, “Seventh” and “Eighth five-year plans for the development of national economy”, through the “National Foundation of Research Programmes for Natural Science” in 1981-1995. The research yielded the following outputs.

In 1990, the research institute CCRI Qiying Min terminated the research project “Characteristics of the adsorption of coal oxygen and its application in the prevention of mine fires”. During the three-year study, 900 experiments were conducted on over 61 coal samples taken from six representative mines, including lignite, bituminous coal and anthracite [10]. The research included the assessment of oxidation of coal mass (the dynamics of spontaneous combustion, tendency classification) and the characteristics of indicator gases (gas images, mine air samplings). The experiments related to the indicator gases of spontaneous combustion confirmed that the tracked released gaseous products of basic types of coal (brown, black and anthracite) contained basic major gases O_2, CO, CO_2, CH_4 and other minor gases from the gas hydrocarbons within a temperature range from low-temperature oxidation to open fire. Their concentrations corresponded to an increase in temperature. For example, the temperature interval of the first occurrence of ethylene was observed for brown coal, ranging from 110 °C to 120 °C, and for anthracite from 120 °C to 140 °C. The interval of the first occurrence of acetylene from 150 °C to 190 °C was observed for brown coal and for anthracite from 250 °C to 300 °C. The samples of brown coal showed the most intensive formation of indicator gases. Different types of coal showed different dynamics of gas releases. CO was determined as a basic indicator gas, then C_2H_4 as a gas indicating the ongoing process of spontaneous combustion, and C_2H_2 – warning gas – as an indicator gas of beginning open fire.

In 1992, within the research [11], 400 samples of all types of coal were tested according to coalification from brown coal to anthracite coal (brown coal, long flame coal, gas coal, fat coal, coking coal, lean coal, meager coal and anthracite). Characteristics of released gases of different lithotypes of coal were evaluated. Relationships of released amounts of CO, C_2H_4, C_3H_6, dimensionless indicators C_2H_4/C_2H_6, C_3H_8/C_2H_6, total amounts of gaseous hydrocarbons of alkanoic series (C_2H_6/C_2-C_4) were evaluated, in particular depending on changes in temperatures and types of coal with the following conclusions:

- Dimensionless indicators of alkane and alkene series were the main indicators of low metamorphic coal (e.g. brown coal, long flame coal, gas coal, fat coal), CO and CO- based indicators were the secondary indicators;

- CO and CO-based indicators were the main indicators of moderately metamorphic coal (coking coal, lean coal and meagre coal), dimensionless indicators based on C_2H_4 and ratios of alkanes/alkenes were the secondary indicators;

Volume LX (2014), No.1
p. 55-65, ISSN 1802-5420

- Indicators of highly metamorphic coal (anthracite), including coal with high contents of sulphur were CO-based and CO-derived indicators only.

The example of graphical research outputs [11] of released gases depending on the temperature and coalification is given in Fig. 1– CO formation and Fig. 2 – C_2H_4 formation.

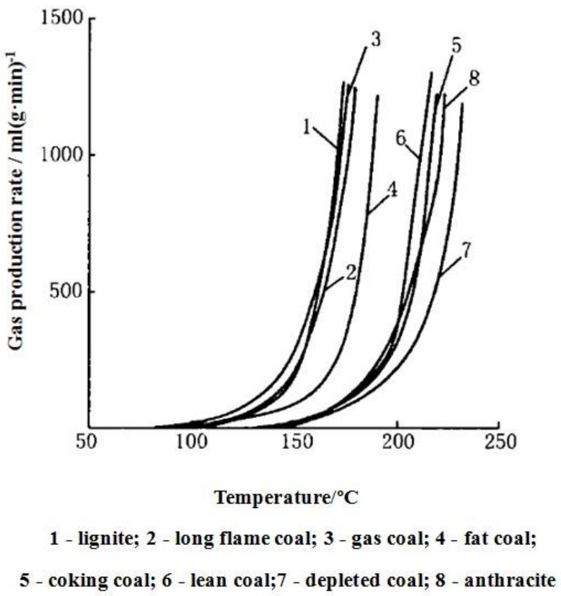

Fig. 1 CO formation according to coalification, [11]

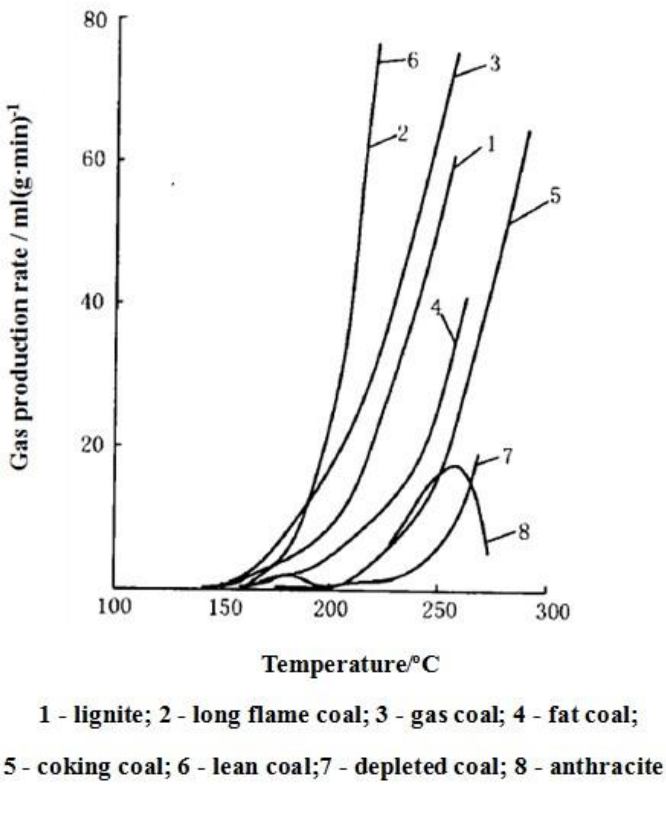

Fig. 2 C_2H_4 formation according to coalification, [11]

Volume LX (2014), No.1
p. 55-65, ISSN 1802-5420

The research also pointed out the necessity to consider a number of influencing factors and specific site conditions such as physical and chemical properties of coal, oxidation ability, point of spontaneous combustion, coal gas capacity, natural conditions, as well as conditions of the mine ventilation [11].

The research [12] investigated gas chromatographic analyses of indicator gases of different micro-petrographic components (virtrinit, durite, fusain) and three different types of coal samples taken at three mines. The research established the relationship of those groups of indicator gases to the mentioned factors, i.e. coal temperature, coal type and its petrography. The indicator gases were divided into three groups:

- Graham indicators, CO, CO/O_2,
- Saturated gaseous hydrocarbon C_2H_6, C_3H_8, C_4H_{10} and dimensionless indicators C_2H_6/CH_4, C_3H_8/CH_4, C_4H_{10}/CH_4, C_3H_8/C_2H_6, C_4H_{10}/C_2H_6,
- Unsaturated gaseous hydrocarbons C_2-C_4 (alkenes), C_2H_2 (alkyne) and dimensionless indicators C_2H_4/CH_4, C_3H_6/CH_4, C_4H_8/CH_4, C_2H_4/ C_2H_2.

The author of [12], He Ping, continued the research of coal samples taken from the Chaili Mine in 1995 [13]. Within the research, e.g. changes in the structure of oxygen functional groups during oxidation were analysed, aliphatic and aromatic hydrocarbons were studied. The experiments confirmed the relevance of the formation of the above first group of indicator gases (CO, CO/O_2) with considerable degradations of oxygen functional groups, and the connection of gas formation of the second and third groups with the loss of aliphatic hydrocarbons of coal mass.

In 2002, when simulating coal oxidation, the author Zhang Guangwen used the sorption concentrator technology for sampling released gases in order to determine the relationship of the contents of CO and C_2H_4 as a reliable indicator [14]. The conclusion of the research found that C_2H_4 can be captured through the concentrator at a temperature of 60 °C which is important at an early indication of early-stage spontaneous combustion, i.e. obtaining valuable time to control its centre. Similarly, in 2003, a research team led by the author Bao Zhonghong detected gases emitted from the beginning spontaneous combustion of coal left in a gob at the Nantun Mine [15]. The experiment confirmed that the use of concentrator technology had enabled to capture ethylene at 60 °C and propylene at 90 ºC. Within the research, the dependency of selected dimensionless parameters on temperature was published, Fig. 3.

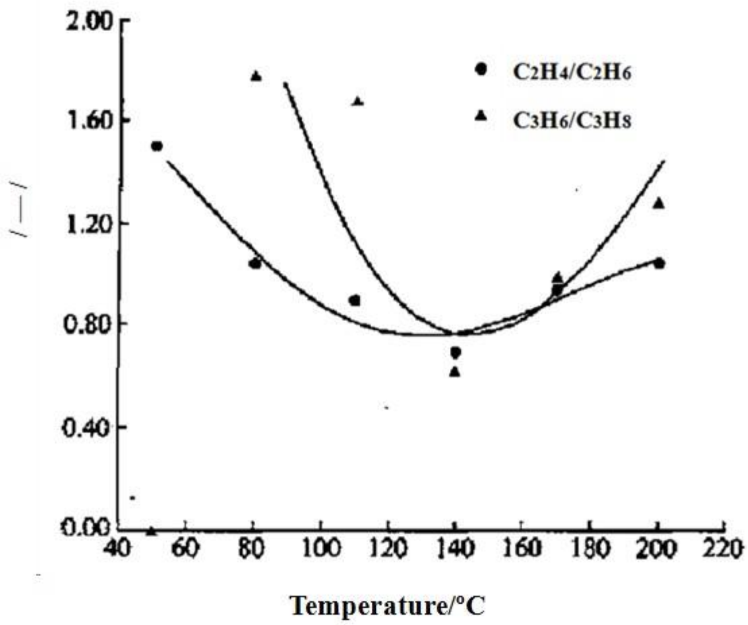

Fig. 3 Dimensionless indicators C_2H_4/C_2H_6 a C_3H_6/C_3H_8 according to [15]

The gas concentrator developed for practical applications was successfully tested in China and then registered as an authorized patent in 2001 under the number CN01238170.5.

Volume LX (2014), No.1
p. 55-65, ISSN 1802-5420

In 2008, a research team led by the author Xiao Yang gathered coal samples from the mines Dongtan, Jiner and Nan Tun [16]. Oxidation tests in seven temperature ranges were supplemented by a thermal gravimetric analysis in order to express weight changes of coal mass during oxidation. The experiments confirmed the characteristic relationship between indicator gases and spontaneous combustion temperature. The critical temperature of the spontaneous combustion process of verified coal types ranged from 60 to 100 ºC with an average of 85 ºC. Carbon dioxides were recommended as indicator gases before reaching the critical temperature, while unsaturated hydrocarbons C_2H_4 a C_3H_6 were identified as characteristic gases from the temperatures above 150 ºC.

In recent years, a large number of articles in the area of research and application of indicator gases of spontaneous combustion of coal have been published in China. Selected information from two of the research papers published in 2012 is presented here. The authors of [17] published the results from the laboratory monitoring of released indicator gases of heat-stressed coal, Fig. 4, with the following conclusions:

- A coal sample begins to release C_2H_6 at a coal temperature of 40 ºC, a linear increase in the concentration of C_2H_6 is observed in the temperature range of 40-110 ºC, the release intensity increases after exceeding 110 ºC, the concentration of C_2H_6 equal to 85.32×10^{-6} was measured at a temperature of 180 ºC;

- A coal sample begins to release C_3H_8 at a coal temperature of 90 ºC and the concentration rises with increasing temperature, and the concentration of C_3H_8 equal to 68.29×10^{-6} was measured at a temperature above 180 ºC.

- A coal sample begins to release C_2H_4 when the coal temperature exceeds 130 °C, the sample gets into a state of intense oxidation and the concentration slightly increases when the temperature of coal reaches 180 °C, the measured concentration of C_2H_4 was $3.735\text{x}10^{-6}$.

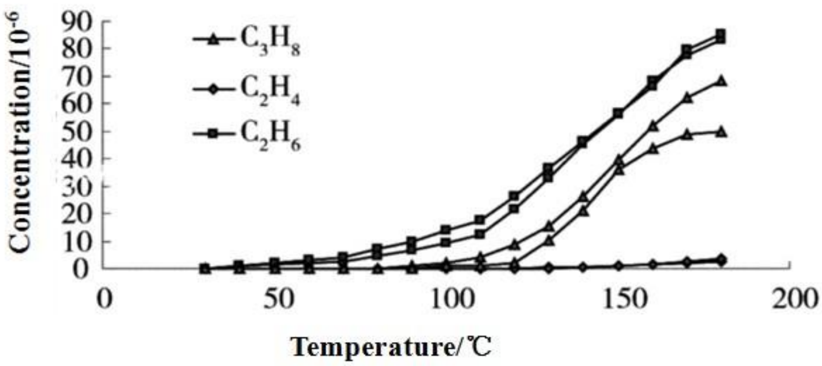

Fig. 4 Formation of C_2H_6 C_3H_8 and C_2H_4 depending on temperature according to [17]

The article [18] describes graphically dimensionless indicators C_2H_6/CH_4 and CO_2/CO, Fig. 5. The authors also state that the formation of CO, CO_2, CH_4, C_2H_6, C_2H_4, C_3H_8 increases with the temperature of coal. They also point out that CO is a characteristic indicator gas of coal spontaneous combustion, which evolves from 40 °C. The formation of CO_2 was captured in the laboratory from 24 ºC. As soon as the temperature exceeded 70 °C, the concentration of CO and CO_2 increased, and the oxygen consumption and the released heat amount rose as well. The authors measured the concentrations of $CH_4 = 334\times10^{-6}$, $C_2H_6 = 4.76\times10^{-6}$ at a lab temperature of 24 ºC . The concentrations of C_2H_6 rose significantly after the temperature had exceeded 110 ºC. The ratio of gases C_2H_6/CH_4 had no regular behaviour; it did not characterize the trend of spontaneous combustion of a coal sample. The value of the gas ratio CO_2/CO decreased with an increase in temperature.

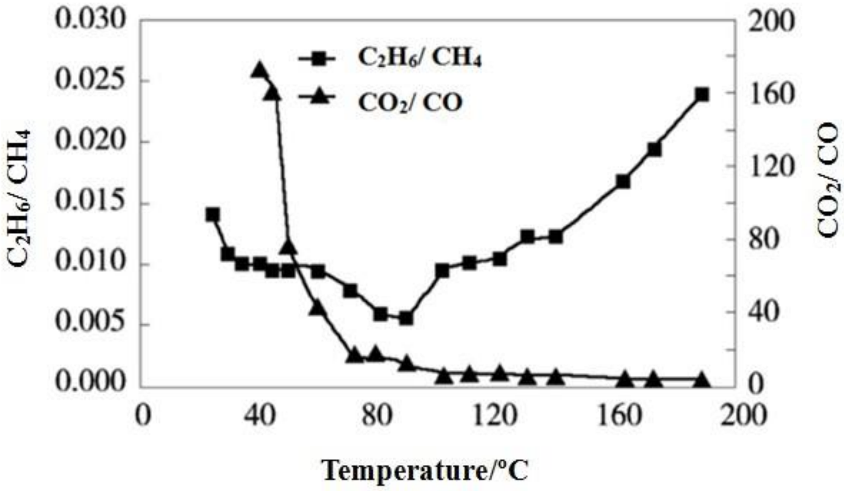

Fig. 5 Behaviours of gas ratios C_2H_6/CH_4 and CO_2/CO according to [18]

China has been dynamically developing the research of a system for preventing spontaneous combustion focused on key indicator gases like CO, C_2H_4, C_2H_2 and other auxiliary gases from the alkane and alkene series since the nineties of the last century. In recent years, hundreds of Chinese mines have been using mine air sampling for chromatographic analyses in accordance with the requirements of mining safety regulations and a number of technical documents in a form of mandatory and recommendatory technical standards.

3 EQUIPMENT AND PROCEDURES

In the fifties of the last century, detection tubes for detecting CO concentrations were widely used in China. In the sixties, some mines started to collect gas samples for analyses in surface laboratories with the intention to improve the accuracy of the analysis of low CO concentrations. Detection sensitivity increased to several tens of ppm from the previous sensitivity of the detection tubes. Portable CO detectors, COY-1 and COY-2 types, were developed. In the seventies, chromatographs started to be used for analysing mine air samples. Simultaneously, works were performed to improve the sensitivity of gas chromatography and to introduce gas monitoring through the use of transport tubes leading from the underground of the mine to the surface (a tube bundle system).

In recent years, the conditions for laboratory procedures for verification of indicator gases of spontaneous combustion gases have been standardized in China. The related equipment used must be equipped with a gas chromatograph, equipment for data logging, a programmable temperature control device for coal, a temperature controller-recorder, a system for dispensing gases, an automatic device for sampling gases, etc. The gas chromatograph must be equipped with a thermal conductivity detector and a flame ionization detector and must be able to analyse the major and minor gases including: O_2, N_2, CO, CO_2, CH_4, C_2H_6, C_3H_8, C_2H_4, C_3H_6, C_2H_2. A heat conductivity detector is used for analysing major gases; the signal should not be less than 0.5 mV. The hydrogen flame ionization detector is designed for the analysis of minor gases.

Currently, a system of program-controlled device intended for experimental observation of spontaneous combustion of coal mass, developed by the research institute CCRI, is widely used. The present apparatus for the oxidation of coal fines may be adjusted within the research by the user for the amount of a coal sample in a range from units of grams to hundreds of kilograms according to the dimensions of the used heat chamber. The device is able to simulate the growth of the spontaneous combustion process temperature to 300 ^{o}C. The system is designed to track the dynamics of coal oxidation, specific oxygen consumptions, heat release amounts, and the amount of released gases. One of the equipment used is shown in Fig. 6. [19].

Fig. 6 One of the program-controlled device for experimental coal oxidation, [19]

The verified coal sample of a set particle size is sucked through the oxidizing medium with a recommended oxygen content of 20.95 % (air) 12%, 10%, 7%, 5% and 3%. The temperature gradient of heating is determined at the following intervals: laboratory temperature-100ºC: 0.5 ºC/min, 100-200ºC: 1.0 ºC/min, 200-350ºC: 2.0 ºC/min, the temperature is registered 6 time per a minute, the time interval for the gas analysis of samples is determined by the formation of chromatographic analysis peaks, but the cycle should not exceed 20 min.

Today, in China, the chromatograph suitable for mining industry, type GC-4008B, is produced. The manufacturer is the Beijing East and West Analytical Instruments Co., (BEWA). The gas chromatograph is intended for coal mines and widely used in China. It is designed as laboratory equipment for the analysis of mine air gas components, it evaluates gas explosiveness, analyses gas components contained in outbursts, analyses spontaneous combustion indicator gases and gases of mine fires – H_2, N_2, O_2, CO, CO_2, alkanes, alkenes, alkynes, etc. It is equipped with a thermal conductivity detector, two flame ionization detectors and four special columns; the lowest analysed concentrations are as follows: CO, $C_2H_2 \leq 0.5$ppm, $C_2H_4 \leq 0.1$ppm, $H_2 \leq 5$ppm. An electron capture detector is designed for the tracer gas SF_6. The chromatograph is equipped with a computer program containing the explosion triangle, Fig. 7 [20].

Fig. 7 Gas chromatograph GC-4008B designed for coal mines, [20].

Tube bundle systems connecting sampling points with analysers on the surface or in mines have been used in China since the eighties of the last century [21]. The mining tube bundle monitoring system based on the GC 8500 type chromatograph was developed in 1995. The analysis of mine gases was improved and extended to gases as follows: O_2, N_2 , CO, CH_4, CO_2, H_2, C_2H_4, C_2H_6, C_3H_8, C_3H_6, C_4H_{10}, C_2H_2, including SF_6 and fire gases [22]. At present, the tube bundle monitoring system JSG-9, developed by the research institute CCRI, is widely spread in China. The system monitors max 16 points at a distance up to 10 km at intervals of analysis of 2-20 min. It tracks caving areas, waste areas, and mine workings; it monitors CO, CO_2, O_2 and other gases of coal heating prevention. The system includes a computer for data backup, special software for the tube bundle monitoring system, a multi-gas analyser, and an assembly of suction vacuum pumps equipped with filters with water separators [23].

4 LEGISLATION AND TECHNICAL STANDARDS

The Chinese State Administration of Work Safety issued the "Coal Mine Safety Regulation" as of 1st November 2001[24]. Several provisions were amended on 14th December 2009. The last amendment, which came into effect on 1 March 2010, regulates indicator gases of spontaneous combustion as follows:

Article 228 – susceptibility of coal to spontaneous combustion is divided into three categories – low, medium and high. The coal susceptibility to spontaneous combustion must be verified before the commencement of mining. The degree of the susceptibility shall be determined by the state supervision in cooperation with a local authorized person. In case of occurrence of seams of middle and high susceptibility, measures of spontaneous heating prevention must be used.

Article 241 – in cases of exploiting seams of medium and high susceptibility, the points of frequent checks shall be carefully determined, a monitoring system shall be established, the indicator gases of spontaneous combustion shall be determined, and heating prevention shall be specified. All detection results must be recorded in the fire safety log, the recorded data must be regularly monitored and evaluated. If the indicators of spontaneous combustion exceed a set threshold limit, the current state will be immediately notified and measures will be taken to address the situation.

In February 2006, the Chinese State Administration of Work Safety issued the recommending technical standard AQ/T 1019-2006 "The method of the gas chromatography analysis and index optimization for mark gases of spontaneous combustion of coal stratum" as a tool for early detection of spontaneous combustion [25]. The standard contains recommendations for choosing indicator gases, their use and the method of analysis. It recommends to monitor CO, C_2H_6, C_2H_4, ratios of alkane/alkene (C_2H_4/C_2H_6), ratios of alkane/methane (C_2-C_4/CH_4), and ratios of alkane/ethane (C_3H_8/C_2H_6, C_4H_{10}/C_2H_6) as indicators of spontaneous combustion.

Coal sampling for laboratory verification of indicator gases is regulated by the Chinese recommended technical standard GB/T 482 "Sampling of Coal Seams" [26], requiring taking at least two coal samples from a characteristic seam area.

Taking gas samples of mine air shall be in accordance with the Chinese binding technical standard MT 142 "Coal Mine Underground Gas Collect Method", [27]. The standard imposes to complete the gas analysis within 12 hours after sampling; it allows to take air samples to bags, bottles or through the use of tube bundle systems.

Tube bundle monitoring systems in China are governed by the recommending technical standard MT/T 757 "General technical conditions of the tube bundle monitoring system for coal spontaneous combustion", [28]. The tube bundle monitoring systems are divided into surface and mine systems. The surface system uses a bundle of gas tubes led out to the surface; in the mine system, the sampling tubes lead to the nearest monitoring chamber and the evaluated data are then transmitted to the surface by the central monitoring system. The standard applies to both mentioned types of tube systems.

5 CONCLUSIONS

China has gained experience with the application of indicator gases in deep coal mining over the last forty years. The beginnings were focused only on basic gases, and then mainly gaseous hydrocarbons were investigated. In recent years, attention has been paid to setting standards for preventing coal spontaneous combustion, the choice of indicator gases of spontaneous combustion suitable for appropriate mines with respecting experimental analyses and practical applications. In order to improve the current knowledge in the detection, monitoring, and the choice of indicator gases of spontaneous combustion, neural network systems, GIS systems, the semiconductor technology, laser adsorption spectroscopy (DLAS), technology of adsorption enriching concentrators, and the technology of infrared spectroscopy were applied within the research, which provide partial results, but yet unapplied on a wider scale.

Several issues still exist in the area of indicator gases of spontaneous combustion and their use in practice as noted by the author of [29], which need to be addressed like:

- Identify different systems of spontaneous combustion indication for specific regional mining conditions, taking into account the genesis of deposits, layer conditions of coal seams, the nature and properties of coal, and the distinct accumulation of reserves in China;

- Establish a multi-level and interdisciplinary engineering dynamic model for risk prevention of endogenous fire occurrence;

- The applications of technologies should be based on a developed multi-cooperating system of knowledge with highly integrated application conditions of early detection of spontaneous combustion under conditions in a given mine.

The choice of appropriate indicators for specific conditions of a coal deposit is important for effective use of the technology of indicator gases of spontaneous combustion. That may reduce the risk of spontaneous combustion and increase safety of workers and operation in coal mines.

ACKNOWLEDGEMENTS

The article was written with support from the Technology Agency of the Czech Republic in the framework of the project No. TA01020351

REFERENCES

[1] GRAHAM, J.I. The normal production of carbon monoxide in coal-mines, *Transaction Institution of Mining Engineers*, vol.60, 1920-21, pp. 222-234.

[2] GRAHAM, J.I. The gaseous products resulting from fires and underground heating.*Transaction Institution of Mining Engineers*, vol.79, p. 92.

[3] KITTAGOWA, T. Detection of underground spontaneous combustion in its early stage with detectors. *In Proceedings of the 10th International Conference of Directors of Safetyin Mines Research*, Pittsburgh, PA, 1959.

[4] Prediction of coal spontaneous combustion. *(Chinese text),* Yuanbaoshan Mine of the Pingzhuang Bureau in Liaoning Province. *Coal Mine Safety*, June, 6/1966, pp. 6-10, ISSN 1003-496X.

[5] Prediction of coal spontaneous combustion in Gushan Mine. *(Chinese text),* Gushan Coal Mine of the Pingzhuang Bureau and Coal Research Institute of Liaoning Province., *Coal Mine Safety*, 2/1977, pp. 31-39. ISSN 1003-496X.

[6] ZHONG, W., LI, F. Graham coefficient (G) for the prediction of spontaneous combustion. *(Chinese text), Coal Mine Safety*, 10/1987, pp. 21-26. ISSN 1003-496X.

[7] WANG, Y. Indicator gases for prediction of spontaneous combustion of coal. *(Chinese text), Coal Mine Safety*, 6/2001, pp. 15, pp. 58. ISSN 1003-496X.

[8] LU, S., SONG, Y. Prediction of coal spontaneous combustion in Chaili Coal Mine. *(Chinese text), Coal Mine Safety*, 8/1995, pp. 5, pp. 13., ISSN 1003-496X.

[9] HUANG, Z. The ratio of alkane to alkene of spontaneous combustion in Liuzhi Mine. *(Chinese text), Coal Mine Safety*, 4/1988, pp. 52. ISSN 1003-496X.

[10] QI, Y., QIAN, G., LUO, H. The coal adsorption flow oxygen combustion characteristics and its application in mine fire prediction. *(Chinese text), Coal Mine Safety*, 9/1993, pp. 1-6, pp. 22, pp. 2-9, ISSN 1003-496X.

[11] LUO, H., QIAN, G. Research of indicator gases of spontaneous combustion associated to different types of coal. *(Chinese text), Coal Mine Safety*, S1/1992, pp. 86-89. ISSN 1003-496X.

[12] HE, P. et.al. Characteristics of gases formation in the process of coal oxidation and coal spontaneous combustion indicator gases choice. *(Chinese text), Journal of China Coal Society*, 6/1994, pp. 636-643, ISSN 0253-9993.

[13] HE, P. et.al. Relationship between the indicator gases produced from spontaneous combustion and coal chemical structure change in the oxidation process. *(Chinese text), Coal Analysis and Utilization*, 4/1996, pp. 12-16.

[14] ZHANG, G., WANG, X. Detect indicator gases of spontaneous combustion. (Chinese text), *Mining Safety and Environmental Protection*, 5/2002, pp. 7-8. ISSN 1008-4495.

[15] BAO, Z. et. al. Detection of concentrated indicator gases of coal spontaneous combustion. *(Chinese text), Jounal of Nanjing University of Technology*, 2/2003, pp. 57-60, ISSN 1671-7627.

[16] XIAO, Y. et. al. Correspondence between the research of indicator gases of coal spontaneous combustion and a characteristic temperature. *(Chinese text), Journal of Nanjing University of Technology*, 6/2008, pp. 47-51, ISSN 1671-7627.

[17] LI, M. et. al. Analysis of coal spontaneous combustion oxidation using multiple indicator gas system. *(Chinese text), Coal Mine Safety*, 1/2012, pp. 19-22, ISSN 1003-496X.

[18] TANG, J., ZHU, J. Experimental research for indicator gases of spontaneous combustion in coal seams at Zhujiadian Mine 4#. *(Chinese text), Coal Mine Safety*, 10/2012, pp. 21-24, ISSN 1003-496X.

[19] Mine Safety Technology Branch of China Coal Research Institute, [online].Updated December 2013 [viewed. 20 January 2013]. Available from: www.ccriaq.com/CCITPageManager.aspx?typeid=117

[20] Beijing East and West Analytical Instruments Co., [online].Updated December 2013, [viewed 21 January 2013]. Available from: www.instrument.com.cn/netshow/SH100293/C14420.htm

[21] Early prediction of mine fire bundle tube continuous monitoring system. *(Chinese text)*. China Coal Research Institute. *Coal Mine Safety*, 6/1983, pp. 9-14, pp. 40. ISSN 1003-496X.

[22] SU, J.: Development status and trends of the mine fire prevention technology. *(Chinese text), Journal of Ji Xi University*, 1/2005, pp. 52-53, pp.60. ISSN 1672-6758.

[23] Research Safety Equipment Branch of China Coal Research Institute, [online].Updated December 2013 [viewed 19 January 2013]. Available from: www.ccrise.cn/show.aspx?id=51&cid=49

[24] Coal Mine Safety Regulations no. 29/2010, State Administration of Work Safety,17-1-2011.

[25] The method of the gas chromatography analysis and index optimization for mark gases of spontaneous combustion of coal stratum. The technical standard AQ/T1019-2006, *State Administation of Work Safety*, 27-02-2006.

[26] Sampling of Coal Seams. The technical standard GB/T 482, *General Administration of Quality Supervision, Inspection and Quarantine of China*. 29-07-2008.

[27] Coal Mine Underground Gas Collect Method. The technical standard T 142, *State Ministry of Coal Industry*. 04-11-1986.

[28] General technical conditions of the tube bundle monitoring system for coal mine spontaneous combustion. The technical standard MT/T 757, *State Ministry of Coal Industry*. 30-12-1997.

[29] LUO, H., LI, Y. Present situation and prospect of coal spontaneous combustion prediction technology. *(Chinese text). China Safety Science Journal*, 3/2003, pp. 76-78, ISSN1003-3033.

RESUMÉ

Samovznícení uhlí je v hlubinných dolech Činy jedním z nejzávažnějších rizik. K jeho minimalizaci je v oblasti aplikace indikačních plynu věnována pozornost v čínském uhelném průmyslu již od šedesátých let minulého století. Prvopočátky výzkumu byly věnovány základním indikačním plynům, od let osmdesátých je výzkum a vývoj v daném směru intenzivně zaměřen na plynné uhlovodíky. Podstatnou roli sehrála čínská státní strategie podpory výzkumu v rámci šestého až osmého „Pětiletého plánu rozvoje národního hospodářství“ v létech 1981-1995, kdy byl realizován výzkumný program „Charakteristika adsorpce kyslíku uhlí a její aplikace v prevenci důlních požárů“, jehož výstupy přinesly poznatky z oblasti indikačních plynů samovznícení v různých směrech, např. ověření charakteristických indikačních plynů uhlí různého stupně prouhelnění, odlišných mikropetrografických složek, výzkum zaměřený na charakteristické podmínky těžených lokalit, ověření technologie plynových koncentrátorů aj. Souběžně byly v čině vyvinuty související technické prostředky, které jsou dnes reprezentovány v Číně vyráběným a široce používaným chromatografem GC-4008B určeným pro uhelné doly. Předmětné čínské poznatky a zkušenosti vyústily postupem doby v řadu závazných a doporučujících technických norem a znění závazného předpisu upravujícího prevenci samovznícení v uhelných dolech.

Článek byl napsán s podporou projektu Technologické agentury České republiky č. TA01020351.