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THE BALANCE OF METHANE AND VENTILATION AS A TOOL FOR METHANE HAZARD ASSESSMENT IN THE AREAS OF LONGWALLS EXPLOITED IN HARD COAL MINES

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ABSTRACT

Purpose

This article presents an algorithm for the current assessment of methane hazards during the exploitation of longwalls in conditions where there are methane hazards. The algorithm has been developed within the framework of the international AVENTO project (Advanced Tools For Ventilation and Methane Emissions Control), carried out in Poland, inter alia, by the Central Mining Institute in cooperation with Kompania Węglowa SA (KW SA). The algorithm was developed based on the analysis of the ventilation-methane balances for longwall areas, based on the data registered by automatic methane sensors and the velocity of ventilating air.

Methods

Multiple research methods were used, such as: observation, a questionnaire and statistical methods. The questionnaire was used for the preliminary determination of methane hazards in the longwalls belonging to the industrial partner (KW SA). The polls were used to obtain relevant information about the hazards and means of prevention taken, such as: the methane content in the seam, the emissions of methane into the exploitation workings, the volume of methane drainage, the ventilation system used, and the amount of ventilation air used to combat the methane hazard. Based on the poll's data, the longwalls with methane emissions in their environment were selected for testing, based on long-term observations of changes in the concentrations of methane in the ventilation air and in the methane drainage net. Methane concentration measurements were based on the values recorded by the methane sensors located in the workings which were considered to be most dangerous. For data processing a statistical method was used. In the research, the average results of the indicated concentrations of methane from the methane sensors were used for the correlation between the average values of methane emission in the region of the longwall or methane drainage, with other parameters, such as absolute pressure changes on the surface, technological processes or cycles in the longwall. For the evaluation of the methane hazard, an indicator was proposed, these being the ratio of the ventilation methane bearing capacity to the critical methane bearing capacity. An increase of this indicator indicates an increase in the level of methane hazard.

Results

On the basis of the average daily value of the methane hazard status indicator, an algorithm for the assessment and visualization of methane hazard in the areas of the active longwalls was developed. The algorithm contains a list of technical and organizational actions which should be taken in the event of unfavourable risk assessment of methane hazard, reflecting very high risk or unsafe conditions for conducting further work.

Practical implications

The proposed algorithm can be used for the ongoing assessment of methane hazard in areas of exploited longwalls in order to support staff in surface control rooms and in ventilation departments.

Originality/value

The current assessment of methane hazard in the areas of longwalls which are under methane conditions by means of the developed algorithm will improve the safety of exploitation.

Keywords

safety, mining, ventilation, methane hazard, analysis, assessment

1. INTRODUCTION

Under the conditions of methane hazard, the primary objective of the ventilation of the mine workings is to provide a sufficient amount of air to ensure the concentration of methane remains below the limit values prescribed by mining regulations. In hard coal mines, methane hazard level

assessment is commonly based on the monitoring and analysis of the absolute methane bearing capacity and the ventilation methane bearing capacity. Absolute methane bearing capacity determines the methane emissions in the environment of the longwall, while the ventilation methane bearing capacity determines the methane emissions into the ventilation air (both values expressed in m^3/min). The development

of research on the absolute methane bearing capacity of longwall environments and attempts to determine the source and intensity of methane emissions were initiated by Karl Winter (1958) some time ago. Later research on methane emission intensity during the operation of the longwalls was conducted by, among others, Klaus Noack (Noack & Hubig, 1976; Noack, 1980). These studies were focused, mainly, on German mines. In Poland, the concept of absolute methane bearing capacity was introduced by Bolesław Kozłowski (1972). It was Kozłowski who outlined the degassing functions of methane bearing seams within the coverage of the impact of the operation (for conditions in Polish mines). These functions are currently being used in the mandatory predictions of absolute methane emissions for longwalls. Currently Poland uses the Central Mining Institute Instruction No 14, titled "Dynamic prediction of absolute methane bearing capacity of the longwalls (technical guide)" (Krause & Łukowicz, 2000).

In order to fully characterize methane hazard in the region, considering only the two aforementioned parameters is not sufficient. In order to accurately determine the status of methane hazard, it is important to refer to the above parameters when considering existing ventilation conditions, i.e. the volume of the air streams in the area of the longwall or the critical methane bearing capacity contained in "The principles of conducting of the longwalls in the methane hazard conditions" – Central Mining Institute Instruction No 17 (Krause & Łukowicz, 2004). Critical methane bearing capacity indicates the limit value of methane emissions in the area of the longwall, which can be combated by means of ventilation and methane drainage. In the project AVENTO, the indicator k_{KW} was proposed, which is the ratio of the ventilation methane bearing capacity to the critical methane bearing capacity, in order to evaluate the methane hazard. On the basis of the average daily value of the methane hazard status indicator, an algorithm for the assessment and visualization of methane hazard was developed.

2. DEVELOPMENT OF THE BALANCING RULES OF METHANE BEARING CAPACITY TAKING INTO ACCOUNT THE AMOUNT OF METHANE DRAINAGE IN THE REGION OF AN ACTIVE LONGWALL

The balance of methane emission in the region of an active longwall should be based on the determination of the total methane emissions in the longwall environment, the so-called absolute methane bearing capacity Q_c . This includes the supply of methane into the longwall environment from the extracted seam and from the layers (seams) located in the stress relaxation zone (from the roof and floor layers present in the desorption zone) (Krause, 2003). In the case of methane drainage in the area of the longwall within the framework of prevention, aimed at limiting the flow of methane into mine workings connected with the area of longwall, in order to balance the total absolute methane content, it is necessary to determine 2 components of total absolute methane content, these being:

- the volume of methane drainage into the methane drainage networks, Q_o ,
- the ventilation methane bearing capacity, Q_{we} .

$$Q_c = Q_o + Q_{we} \text{ m}^3/\text{min} \quad (1)$$

The volume of methane drainage into methane drainage networks Q_o (m^3/min) refers to the amount of methane drained from the rock mass area under the influence of drainage holes. Due to the fact that the holes are made in the zone of exploitation impact, a significant share of methane captured by methane drainage networks derives from the surrounding methane-bearing layers located in the stress relaxation zone. The volume of methane drainage into the methane drainage network can be determined based on individual (manual) measurements of methane concentration and the flow rate of the gas mixture in the methane drainage pipeline released from the ventilation area. These measurements are performed periodically using a measuring orifice plate. The volume of methane drainage can also be measured continuously with the use of automatic sensors of methane drainage parameters installed in the pipeline. In order to compare the volume of methane drainage to normal conditions it is also necessary to measure the pressure and gas temperature in the pipeline. For the normal parameters of gas, which is similar to normal conditions, the volume of methane drainage into the methane drainage network Q_o can be determined based on the simplified dependence (2):

$$Q_o = 0.01n_oQ_g \text{ m}^3/\text{min} \quad (2)$$

where:

n_o – concentration of methane in the mixture of gases in the methane drainage pipeline, %

Q_g – flow rate of the mixture of gases in the methane drainage pipeline, m^3/min .

The ventilation methane bearing capacity Q_{we} (m^3/min) is the volume of methane emission into the ventilation air flowing in workings in the region of the longwall. Within the area of longwalls the most intense emissions of methane into ventilation air occur mainly in the exploitation workings (longwall) during the mining process and the other workings which are in direct vicinity of the gobs. The volume of methane concentration in mine ventilation air can be found by calculating the difference between the flow rate of methane released with the air from the area of the longwall and the flow rate of methane supplied with the ventilation air to the area from other sources (3)

$$Q_{we} = 0.01(c_2Q_2 - c_1Q_1) \text{ m}^3/\text{min} \quad (3)$$

where:

c_2 – methane concentration in the air at the outlet in the area of longwall, %

c_1 – methane concentration in the air at the inlet in the area of longwall, %

Q_2 – air flow rate at the outlet in the area of longwall, m^3/min

Q_1 – air flow rate at the inlet in the area of longwall, m^3/min .

Flow rate at the inlet and outlet in the longwall area should be determined by individual measurements of excavation cross-sections and air velocity by means of an anemometer adopting the traverse method in daily periods or more frequently e.g. after adjusting the ventilation network.

The concentration of methane in the air at the inlet and outlet of the longwall area (c_1 , c_2) should be determined based on manual measurements using individual instruments e.g. methanometers, or based on air samples used for precise

laboratory analysis. Indications of automatic methane monitoring after their prior calibration (Fig. 1) can also be used for the analysis of methane concentration.

An example of the use of automatic methane monitoring to determine shaping changes in the ventilation methane bearing capacity during one day is shown in Figure 2.

On the basis of the changes in methane concentration in mine ventilation air which take place during one day, it is

possible to determine the average daily value of the ventilation methane bearing capacity of a longwall. In the case of longwall No 1, the value is 12.6 m³/min. For the analysis of methane content balancing over longer periods e.g. during a month or a year – the average daily ventilation methane bearing capacity (Q_{we}) can be correlated with the value of methane drainage (Q_o), which is less frequently measured, typically once a day (Fig. 3).

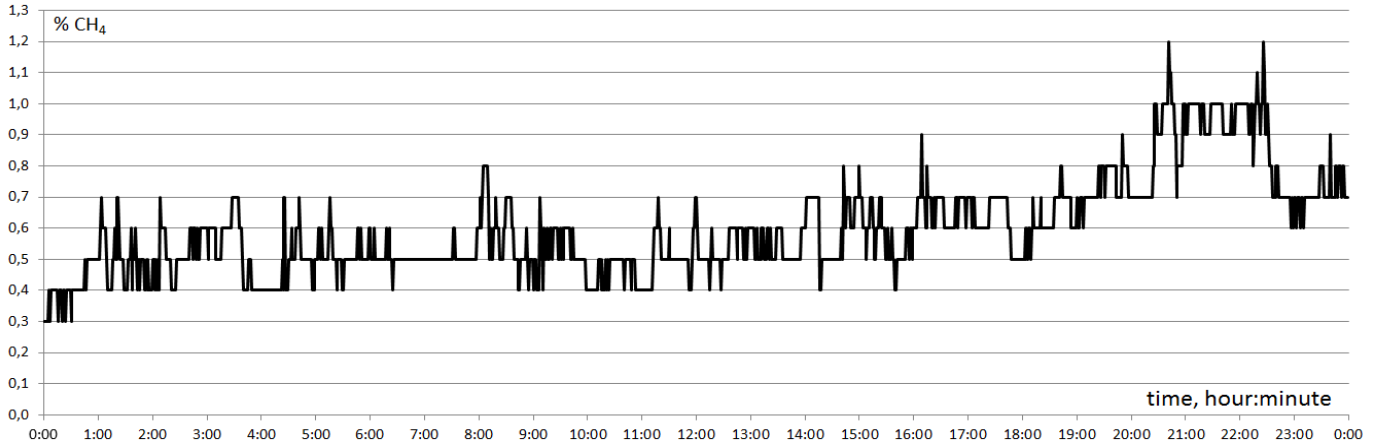


Fig. 1. Graph of the concentration of methane in the return air released from the region of longwall No 1 on 20.09.2013 (based on the registered values of the concentration of methane using an automatic methane sensor)

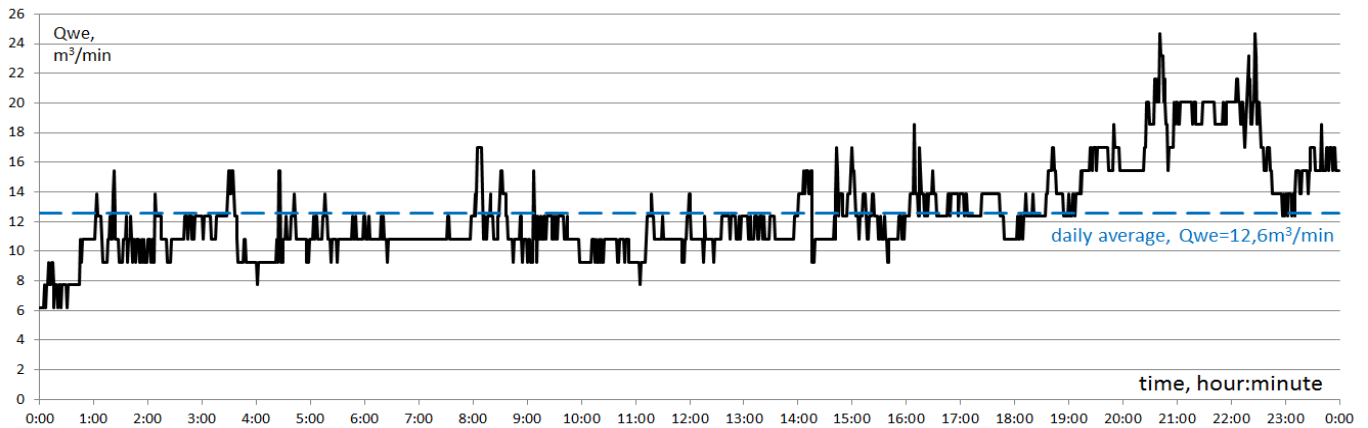


Fig. 2. Graph of the methane emission into the ventilation air released from the area of longwall No 1 (ventilation methane bearing capacity Q_{we}) on 20.09.2013

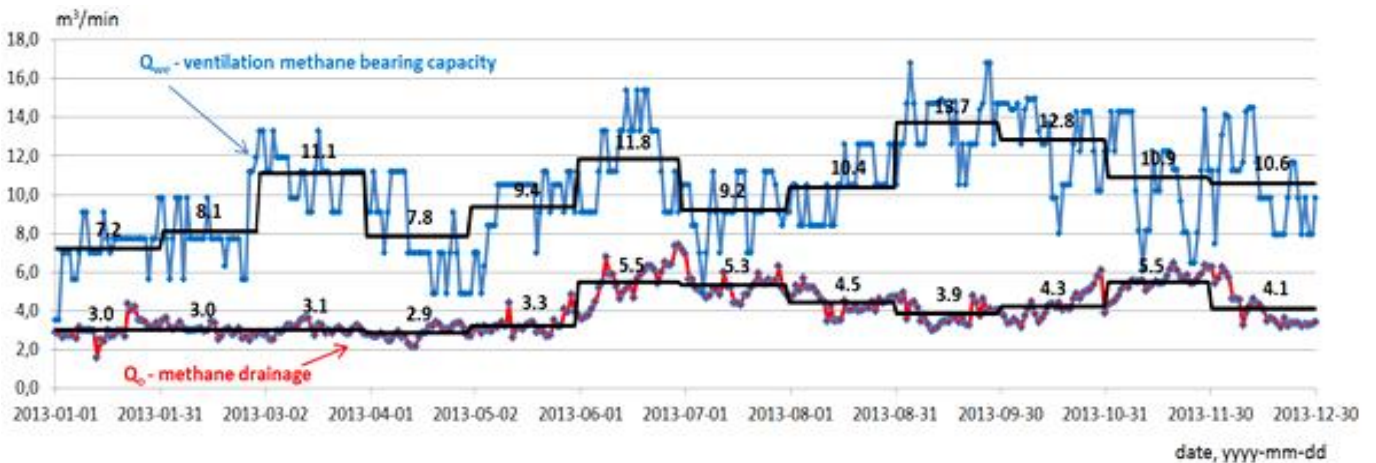


Fig. 3. Balance of the methane bearing capacity divided into ventilation methane bearing capacity (Q_{we}) and methane drainage (Q_o) based on the daily values and average monthly values on an annual basis for longwall No 1

Using the methodology outlined above, a balance of the total absolute methane content was carried out (Q_c) for 14 active longwalls exploited in Kompania Węglowa SA (KW SA) in 2013 in the hard coal mines Bielszowice and Rydułtowy-Anna. Methane balance was divided into ventilation methane bearing capacity (Q_{we}) and the volume of methane drainage into methane drainage network (Q_o).

Daily methane concentrations were determined on the basis of indications of automatic methanometry verified by control ventilation-methane measurements. In contrast, the volume of methane drainage in the areas of longwalls, was examined using a measuring orifice plate. The analysis of the methane bearing capacity included both, monthly periods as well as longer periods corresponding to the exploitation of longwalls carried out in 2013. The cumulative balance of the total absolute methane content (Q_c), ventilation methane bearing capacity (Q_{we}) and the volume of methane drainage in the methane drainage network (Q_o), for 14 active longwalls exploited in 2013 in hard coal mines Bielszowice and Rydułtowy-Anna, is presented in Table 1. The airflow quantities depend on methane emission and the parameters of the ventilation net.

The analysis of the methane bearing capacity included the periods corresponding to mining activity at the longwalls in 2013. Moreover, Table 1 provides information on the analysed periods of exploitation, the longwall ventilation system used, the volume of air flow rate in the area and panel lengths, which in part may be an indicator associated with the length of the gobs complex.

Table 1. Cumulative balance of the methane bearing capacity for 14 longwalls in the year 2013

No of longwall	Analysed period of time in 2013	Average ventilation methane bearing capacity	Average methane drainage	Absolute methane bearing capacity	Ventilation system	Air flow rate	Panel length
		m ³ /min	m ³ /min	m ³ /min		m ³ /min	
	(from month to month)						
1	01–12	10.3	4.0	14.3	U	2100	1410
2	01–12	1.6	0.0	1.6	U	1150	570
3	07–12	1.5	0.0	1.5	U	1200	595
4	01–12	15.1	17.6	32.7	Y	1000 + 900	960
5	06–12	8.7	0.0	8.7	U	1510	420
6	05–12	0.9	0.0	0.9	U	1600	160
7	02–12	5.1	2.6	7.7	U	1040	1210
8	01–07	5.9	0.0	5.9	U	1120	1065
9	01–12	4.1	1.4	5.5	U	1030	777
10	08–12	2.0	0.9	2.9	U	1100	1030
11	01–09	4.2	1.4	5.6	U	990	800
12	01–11	4.1	0.0	4.1	U	1600	555
13	01–12	5.7	2.6	8.3	U	1150	1035
14	01–12	4.5	1.6	6.1	U	1040	850

3. THE PRINCIPLES OF METHANE HAZARD ASSESSMENT IN THE AREA OF EXPLOITED LONGWALLS

Analysis of the level of hazard in the longwalls can be carried out based on analysis of the dynamics of the registered values of methane concentration in excavations or based on an analysis of the indicators of a methane hazard.

The analysis of the changes in methane concentration, over set time periods, in excavations is usually easy to interpret, because the exceeding of the threshold of methane concentration, this being 1.5% or 2% (Regulation, 2002), clearly proves an increase in the hazard. Unfortunately, this analysis

is limited to selected places where automatic methane sensors were installed. On the other hand, analysis of the level of methane hazard in longwalls, based on sensitive analysis of pre-defined indicators characterizing the state of methane hazard, is partly based on the theoretical assumptions outlined below. For the analysis and assessment of methane hazard in normal ventilation conditions, in accordance with Polish regulations (Regulation, 2002), the hazard indicator k_{KW} is defined as the ratio between the ventilation methane bearing capacity Q_{we} and the criterion of the absolute methane bearing capacity V_{KR} (5) (Krause & Łukowicz, 2004):

$$k_{KW} = \frac{Q_{we}}{V_{KR}} = \frac{Q_c(1-E)}{V_{KR}} \quad (4)$$

where:

Q_c – total absolute methane bearing capacity of a longwall, m³ CH₄/min

E – efficiency of the methane drainage of the exploited longwall

V_{KR} – the critical absolute methane bearing capacity for the longwall, m³/min (according to formula 5)

$$V_{KR} = \frac{V_p c_m k}{100n} + \frac{V_L \left(\frac{c_m}{n} - c_p \right)}{100 - \frac{c_m}{n}} - V_{D(CH_4)} \quad (5)$$

where:

V_p – volume of the air flow rate flowing through the longwall, m³/min

V_L – volume of the air flow rate supplying the outlet from the longwall – the auxiliary air duct (longwall U) or air flow rate supplying the longwall (Y type ventilation), m³/min

c_m – acceptable content of methane in the air current of the outlet, $c_m = 1.5\%$

c_p – content of methane in the air supply,

k – factor determining the non-uniformity of the velocity distribution in the longwall, $k = 0.85$ (Krause & Łukowicz, 2004)

n – factor determining the non-uniformity of methane emission, $n = 1.55$ (Krause & Łukowicz, 2004)

$V_{D(CH_4)}$ – the amount of methane flowing into the longwall from other sources, m³/min.

The indicator of the state of the methane hazard k_{KW} takes into account methane emissions in the longwall environment, the so-called total absolute methane bearing capacity, methane preventive measures i.e. intensity of longwall ventilation, methane drainage of the rock mass as well as other factors such as the uneven distribution of air velocity in the longwall and the unevenness of methane emission and the amount of methane flowing into the longwall from other sources. An increase of the indicator means that there is a high level of methane hazard. It can be assumed that by exceeding the k_{KW} indicator by the value of 1 means that there is a very high methane hazard present at the longwall. Detailed classification referring to the status of methane hazard in longwalls based on the value of the criterion of k_{KW} , established *a priori*, is given in Table 2 (Wierziński, 2013).

Table 3 provides the value of the indicator k_{KW} for 14 longwalls determined on the basis of the average values of the parameters across the whole period of longwall activity.

Table 2. Classification of the state of the methane hazard in the longwalls based on the value of the indicator k_{KW}

Value of the indicator of methane hazard for the longwalls, k_{KW}	Rank of methane hazard at the longwall
≥ 1.0	Dangerous longwalls, Very high methane hazard
$< 0.8-1.0$	High methane hazard
$< 0.5-0.8$	Moderate methane hazard
$< 0.2-0.5$	Low methane hazard
< 0.2	Lack of hazard

Table 3. Average values of the parameters of methane hazard present in longwall activity in 2013

No of longwall	Q_c	Q_{we}	E	V_p	V_{KR-O}	k_{KW} indicator
–	m ³ /min	m ³ /min	–	m ³ /min	m ³ /min	–
1	14.3	10.3	0.29	1440	23.6	0.61
2	1.6	1.6	0.0	1100	9.0	0.17
3	1.5	1.5	0.0	1200	9.9	0.15
4	32.7	15.1	0.54	900	37.2	0.88
5	8.7	8.7	0.0	1510	12.4	0.71
6	0.9	0.9	0.0	1600	13.2	0.07
7	7.7	5.1	0.34	1040	12.9	0.60
8	5.9	5.9	0.0	1120	9.2	0.64
9	5.5	4.1	0.25	1030	11.4	0.48
10	2.9	2.0	0.31	1100	13.1	0.22
11	5.6	4.2	0.25	990	10.9	0.52
12	4.1	4.1	0.0	1600	13.2	0.31
13	8.3	5.7	0.31	1150	13.8	0.60
14	6.1	4.5	0.26	1040	11.6	0.53

The conducted analysis of the state of methane hazard based on the method of comparing the different values of the indicator k_{KW} for the longwalls shows that the highest risk of methane $< 0.8-1.0$ occurs in longwall No 4. This longwall, due to the ventilation system being used was able to operate in conditions of high methane hazard. After analysing the results, it can be concluded that the remaining longwalls have a moderate level of methane hazard. For these longwalls the value of the indicator is in the range of 0.5 to 0.8. The remaining longwalls are run in conditions of low or a complete lack of methane hazard.

4. DEVELOPMENT OF AN ALGORITHM FOR THE ASSESSMENT AND VISUALIZATION OF METHANE HAZARD IN THE AREA OF LONGWALLS

The algorithm used to assess and visualize methane hazard was based on the designation of an average daily value to the methane hazard status indicator $k_{KW(d)}$. The algorithm is shown pictorially in block diagram form in Figure 4. According to the scheme, the calculation of the value of the indicator $k_{KW(d)}$ requires, inter alia, readouts of the instantaneous data from monitoring systems, mainly methane systems and automatic anemometry i.e. methane concentration at the inlet of the longwall (c_1), at the outlet of the longwall (c_2), air velocity in the bottom and top gates of the longwall (w_1 , w_2), the volume of methane from the automatic sensor methane high concentration in the methane drainage pipeline (Q_o). The results of the sensors which record parameters, such as the concentration of methane in the air and the concentration of methane in methane pipelines, require periodic inspections. Similarly, the air velocity sensors require periodic calibration.

Based on the calibrated measured values, it is possible to calculate the instantaneous state of the ventilation parameters, i.e. the flow of the air current in the longwall (V_p) and the flow of the refreshing air stream (V_L). In the same way it is possible to calculate the parameters of methane hazard in-

stantaneously, i.e. the ventilation methane bearing capacity (Q_{we}), the absolute methane bearing capacity (Q_c), methane drainage efficiency (E).

The next step is to perform calculations of the average daily values of these parameters, based on the values obtained instantaneously. In addition, the coefficient of the inequality of methane emission $n_{(d)}$ (according to the formula 6) is calculated and on this basis so is the value of the criterial absolute methane bearing capacity $V_{KR(d)}$ (by formula 5).

$$n_{(d)} = c_{1\max}/c_{1(d)} \quad (6)$$

where:

$c_{1\max}$ – the maximum concentration of methane at the outlet from the region recorded in the last 24 hours, %

$c_{1(d)}$ – the average daily concentration of methane from the recorded values at the outlet from the region for the last 24 hours, %.

In the algorithm, the assessment of the methane hazard is based on determining the average daily value of the methane hazard status indicator $k_{KW(d)}$ and comparing it to limit value 1. It was assumed that in cases where the indicator value is equal or greater than the threshold of 1, a state of methane hazard in the longwall will be assessed as very high and potentially dangerous, making the continuation of the exploitation in the longwall impossible. This situation will lead to a required temporary halt of exploitation in the longwall until a reduction of methane hazard level. It was assumed that the state of methane hazard in the longwall can be accepted only if the indicator value is less than the limit value. It is also important to determine the indicator's trends over time. The unfavourable situation may occur when the current average daily value of the methane hazard status indicator $k_{KW(d)}$ is clearly higher than the average daily value of the previous day $k_{KW(d-1)}$, which would clearly indicate an increase in methane hazard ($k_{KW(d)} > k_{KW(d-1)}$). In this case it is necessary to identify the source of this issue. For example an increase in the ventilation methane bearing capacity and/or a decrease in the criterial absolute methane bearing capacity, which in turn results from a decrease in the intensity of ventilation and/or an increase in the inequality of methane emission, when $n_{(d)} < n_{(d-1)}$.

In cases of a decrease in the amount of air in the region, the network must be regulated in such a way as to restore the original intensity of the ventilation of the longwall. On the other hand, in cases where there is an increase in the inequality of methane emissions (coefficient n) it is advisable to take additional technical and organizational measures that have an effect on the extraction technology in the longwall (I) or improve the stability of ventilation in the area (II).

I. The organizational and technical activities affecting extraction technology in the longwall:

- Extension of the cycle duration time of the coal shearer.
- Reducing the depth size of the shearer web.
- Alternating mining in the longwall, for example every other shift.
- Reducing the shearer's speed when approaching the ventilation gate at a distance of less than 30 m in order to limit the flow rate of methane from the gobs.

II. Activities which improve the stability of ventilation in the longwall area:

- Increasing the reliability of the air distribution regulators, for example: ventilation airlocks in double configuration, mechanical safeguards which prevent the opening of two airlocks at the same time, additional protection against damage to the dams, the elimination or reduction of potential factors that affect the working of ventilation dams (for example a change of transport route), etc.
- Monitoring the ventilation airlocks, for example, by installing automatic sensors.
- Installing absolute air pressure sensors to allow further analysis of pressure changes in the vicinity of the gobbs.
- Maintaining the ventilation reserve, which, if necessary, can be utilized quickly.
- Increasing the reliability of additional ventilation devices, such as baffles and injectors for the dilution of methane in longwall area.

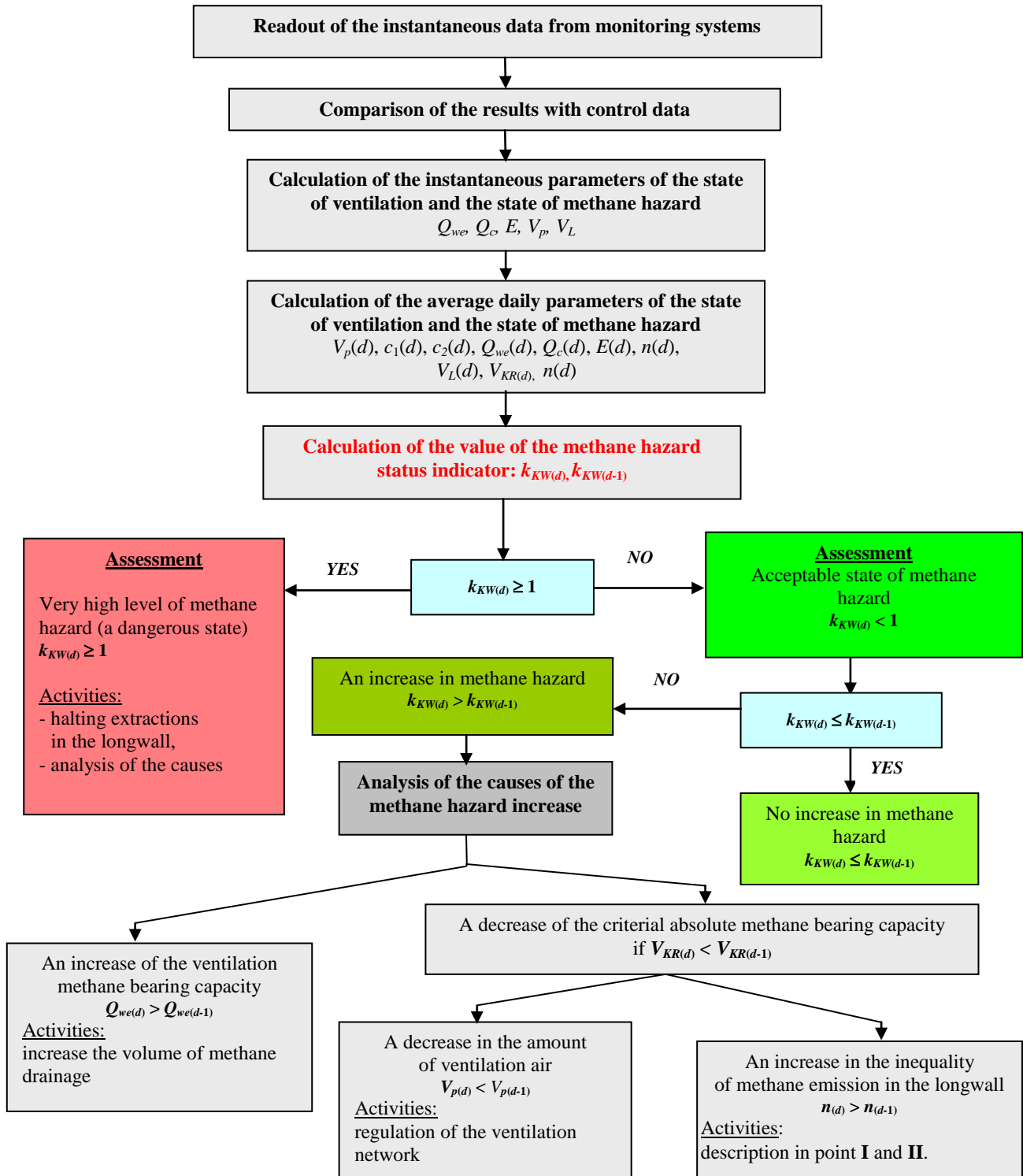


Fig. 4. The algorithm for the assessment and visualization of methane hazard based on the designation of an average daily value to the status indicator methane hazard $k_{KW(d)}$

5. CONCLUSIONS

1. The assessment of methane hazard (not explosion hazard) in the areas of the longwalls exploited in methane mines, in normal and not accidental situations, should be based on the methane-ventilation balance, which takes into account both the volume of methane emissions into the environment of the longwall, as well as the actual ventilation conditions in the region.
2. For the evaluation of methane hazard in normal ventilation conditions and in accordance with Polish regulations (Regulation, 2002) the indicator k_{KW} has been proposed, which is the ratio of the ventilation methane bearing capacity to its limit (i.e. the critical methane bearing capacity) above which combating of methane hazard using the ventilation means is insufficient.
3. The indicator used is comprehensive and includes both methane emission into the environment of the longwall, methane preventative measures as well as factors, such as, uneven air velocity distribution in the longwall and the irregularity of methane emissions. The increase of this indicator translates to a rise in the methane hazard. It can be assumed that by exceeding the k_{KW} indicator by the value of 1 means that a very high methane hazard in the longwall is present.
4. Analysis of methane hazard for the 14 selected longwalls, based on an average of their periods of activity, shows that the highest state of methane hazard occurred in only one longwall ($k_{KW} = 0.88$), which places it in the high methane hazard classification.
5. The algorithm for the assessment and visualization of methane hazard was based on the designation of an average daily value of the methane hazard status indicator $k_{KW(d)}$. According to this algorithm, the calculation of the value of the indicator $k_{KW(d)}$ requires, inter alia, readouts of instantaneous data from monitoring systems, mainly methane systems and automatic anemometry, and the calibration of the data with the results of the control measurements, the calculation of the instantaneous and average daily parameters of the state of ventilation and the state of the methane hazard. It was assumed, that the assessment of methane hazard will be based on determining the average daily value of the methane hazard status indicator $k_{KW(d)}$ and comparing it to the limit value 1. It was assumed that in cases where the indicator value is equal or greater than the threshold of 1, the state of methane hazard in the longwall will be assessed as very high and potentially dangerous, making the continuation of the exploitation in the longwall impossible. In the algorithm for the visualization of methane hazard conditions indicating

a change of the hazard state (increase or decrease) and a detailed list of technical and organizational measures to be taken in order to reduce the level of this hazard were presented.

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