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METHANE RISK ASSESSMENT IN UNDERGROUND MINES BY MEANS OF A SURVEY BY THE PANEL OF EXPERTS (SOPE)

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ABSTRACT

Purpose	The purpose of the paper was to develop a method of methane risk assessment in order to fulfil the technical-organizational and legal requirements for occupational risk assessment in mines. Methane hazard and associated risks of the effects of ignition and/or explosion of methane is one of the most severe natural hazards.
Methods	Heuristic methodology based on the Delphi approach and a group survey by a panel of experts, which was named SOPE, was used to assess the magnitude of methane risk. The adopted tools for assessing the current state of methane risk factors and their possible accident consequences were targeted surveys, with the participation of experts representing, mainly, engineering-technical personnel of mine ventilation service. The objectivity and independence of the judgment of the experts was checked by determining indicators of the degree of the experts' unanimity, indicators of their competence as well as indicators of the validity of their evaluations. The subject matter of the study of methane hazard were five longwall areas of the "A-Z" twin-mine (after the merge of two mines: Mine A and Mine Z), three longwalls operated towards plant A and two longwalls operated towards plant Z. For the assessment of each area of the mine, a Methane Risk Assessment Questionnaire consisting of 4 assessment cards, was used. The cards included four areas of the studied risk factors, i.e. factors shaping the methane hazard (17 factors), the activity of the methane ignition initiators (19 factors), detection and prevention of methane risk (16 factors) and possible human and material losses (13 factors).
Results	The evaluation of 65 factors affecting the causes and consequences of the methane risk in the exploitation area under analysis, was conducted in accordance with the procedure of the adopted method, based on the proposed algorithm. Assessments by experts were used to calculate the indicators of the magnitude of methane hazard for each group of factors separately.
Practical implications	A practical example of the application of this method is incorporated in chapter four of this paper, which also discusses the results of the conducted research.
Originality/value	The obtained values of the indicators of methane risk assessment and analysis of their changes showed that the proposed method can be an important element in the design and construction of a modern methane safety system in coal mines. It provides the possibility of controlling this risk and enables the minimization of its consequences in accordance with the criteria of their acceptance, adopted in this paper. The method does not replace the currently used methods of methane risk assessment, but complements them in a significant and modern way.

Keywords

methane hazard, risk assessment in mine, experts

1. INTRODUCTION

Methane hazard is currently the most dangerous and dominant natural hazard in Polish hard coal mines. The reasoning behind this view is expressed in opinions and publications, especially those which present quantitative and qualitative data, technical, organizational and economic changes that significantly influenced the conditions of mining extraction in

methane bearing seams (Konopko, 2013; Krause, 2012; Krause & Łukowicz, 2001). The risk of ignition and methane explosion effects the environment increased in a specific way, despite the fact that prevention methods conducted in order to combat methane hazard has resulted in the reduction of the number of hazardous situations and incidents in recent years. However, the obtained results cannot be regarded as satisfactory, especially due to increasing seam saturation with

methane which increases as the depth of exploitation increases, which in the conditions of the increasing concentration of extraction carries interrelated risks to persons and property (Międzynarodowa Organizacja Pracy [MOP], 2006; Krzemień & Krause, 2000). Collective accidents caused by natural hazards are particularly severe. Analysing the changes that take place at various levels of theoretical study and their connection with the description of methane hazard, a diversity of views and ideas on the course of gas-dynamic phenomena and gas-geodynamic phenomena occurring as a result of mining activities, can be observed. This applies to many aspects of the problem such as the stability of the phenomena, the possibility of accurate measurement, the predictability of the effects of hazard occurrence and many other conditions. The dominant research approaches in methane hazard are mechanicism and reductionism, used for many years in the description and explanation of processes and phenomena occurring in the rock mass and the surrounding and the workings constituting the miners' workplace. This applies particularly to methods and quantitative models based on classical physical-mechanical and thermodynamic theories. Not minimizing the priority of their scientific role and also practical significance, the heuristics methods outlined in this paper should also be taken into account as important new tools which enrich our understanding of the reasons for methane outflow and gas-dynamic phenomena occurrence, and in particular of their possible effects. Science-based prediction of the effects is the primary aim of the evaluation system alongside methane risk reduction. This follows directly from the definition of occupational risk.

A rock mass with workings made in it and the phenomena that occur there, as well as the employed personnel form an integrated system exhibiting some overall features aimed at creating a kind of biological homeostasis. This system seeks to maintain the balance and stability of working conditions resistant to diverse impacts and environmental disruption. Relating this view to methane hazard, it can be assumed that the areas of the longwalls with ventilation-connected workings, the phenomena of sudden outflows from post-exploitation goaf and threats related to these, as well as the possible effects of accidents, form an integrated safety system. In this system, the methane risk system is one possible subsystem. The system of methane hazard is aimed at maintaining the workings of the longwall environment, the conditions of the relative stability of safety at work owing to increasingly perfect systems of monitoring, control and operation as well as procedures for responding in cases of extreme danger. The use of the system approach in conditions of methane hazard occurrence is a reference to the developing science regarding safety systems, in some studies this is also referred to as a "system approach assessment of hazard potential and risk management" (Krause & Łukowicz, 2001; Krzemień, 1991, 1992). Safety systems includes, among others, studies of potential states of emergency of the whole system and its component subsystems. Information-forecasting models play an important role here. They should be understood as verified theoretical and practical knowledge derived from measurements as well as quantitative and qualitative observations, necessary for the continuous control of hazard level and risk anticipation of their consequences. In this approach, the model must be understood not as a repre-

sentation but as an adopted mode of action. The system approach to the analysis of gas-dynamic phenomena occurring in the rock mass reveals their integrity and dynamics. In this light, the arrangement of workings including the area of longwall and its surroundings can be regarded as a holistic system, the phenomena taking place in it as a dynamic phenomena governed by the laws of thermodynamics of irreversible processes – non-linear thermodynamics. The description of the phenomena occurring in the rock mass is the trend with which the development will depend upon the achievements of synergists, science which integrates detailed phenomena forming independent theories of formation and the impact of these phenomena (e.g. output of rocks and gases – rock burst – methane – coal dust explosion) in systems far from the state of equilibrium (Kabiesz, 2001; Krzemień, 1991).

In parallel with the improvement of the theoretical description of the dynamics of gaseous phenomena occurring in the rock mass, methods allowing us to exploit the huge potential of knowledge and information about the course of these phenomena observed and documented in coal mines, should develop. The qualitative information obtained should be collected, archived and processed in a formalized way with the aim of improving the effectiveness of the safety system performance against the methane hazard occurring in the mine. Such chance is created by dynamically developing quality-heuristic models that using computer technology and databases on the basis of the programming will allow for the processing of qualitative information about the state of the methane hazard into quantitative information and aggregating them into effective warning information of the possibility of the occurrence of a hazardous phenomena and its potential effects.

2. OCCUPATIONAL RISK AND METHANE HAZARD

The risk of methane hazard is closely related to the emission of methane from underground workings as a result of mining operations/activities with the participation of employees in their workplaces. The risk is the possibility of the occurrence of adverse effects within a certain time and under certain circumstances (Kowalik, 1996; Krzemień & Krause, 2000; PN-N-18002, 2011). Due to the fact that the result precedes the driving force and the accompanying circumstances which are simultaneously co-occurring and the conditional reasons (theory of events), the primary cause of the risk of ignition and methane explosion is the gas factor i.e. the presence of methane, and conditional causes: the initial ignition and the oxidizing agent. Methane hazard is related to the genetic properties of the methane factor such as flammable and explosive properties, always potentially dangerous to workers and the surroundings. By definition, a hazard is a potential feature and internal property of each dangerous factor, often imperceptible, until the moment of the property disclosure of the phenomenon occurrence and occurrence of loss. The hazard, and precisely a hazard to human health is synonymous with danger. Such properties are often unnoticed or ignored until the disclosure of their consequences. Occupational risk is related to accidents, health, and tangible and material effects. The concept of loss expressed in financial institutions is related to these effects. Losses are an important

part of the costs of the plant's operational activity, it is possible reduced them with skilful risk management.

The problem of losses, was one of the reasons for introducing a legal obligation to assess and reduce the occupational risk by organizations and enterprises in EU countries. The excessive size of these losses, was one of the reasons for defining the concept of occupational risk and the introduction of the obligation to assess and reduce the risk by all employers (MOP, 2006; PN-N-18002, 2011).

A measure of occupational risk R is a function of the probability of undesirable hazardous incidence associated with the impact of risk P and the probability of the effects of E , including losses suffered as a result of this incidence – formula (1)

$$R = f(P, E) \quad (1)$$

The most tragic and socially severe consequences of methane ignition following its methane ignition are personal and material (property) losses.

As a result of the spontaneous ignition of coal in a longwall goaf, followed by methane or other ignition initial, there is a need for the periodic isolation of the longwall environment from ventilation-active workings, which is connected with passive prevention against fire. Periodic insulation with explosion-proof stoppings in the longwall region contributes to the cooling of the rock mass in the dammed space before the opening and ventilation works of the area are commenced and further exploitation is continued. Often the extensive period of prevention is the cause of the abandonment of reconstruction works aimed at launching further exploitation of the longwall. In this case, damage to the property occurs which reflects the value of the assets constituting the longwall equipment, and mechanical and electrical infrastructure related to it. Interpretation of the components of the formula (1) is as follows: component P means possible, likely causes of risk, and component E , possible, likely effects of risk. The subject and purpose of occupational hazard assessment is the employee on whose behalf and for whom, occupational hazard assessment is performed. In the risk assessment, the terms: risk calculation and risk evaluation can be used. Calculation of risk means the designation of a probability value of dangerous event occurrence e.g. associated with the ignition and explosion of methane. Most often it is the probability of the frequency. Risk assessment is the determination of the numerical size of risk based on the opinion of evaluation experts (Krzemień, 1990).

In practical applications the indicator formula (2) of occupational hazard magnitude M_R is used as the product of:

$$M_R = M_H M_L M_E \quad (2)$$

where:

M_H – indicator (magnitude) of the state of hazard estimation as a possible cause of the risk,

M_L – indicator (magnitude) of the risk of effects of hazard estimation including the size of the possible human losses,

M_E – indicator (magnitude) of the probability of exposure to risk (dimensionless expression of the duration of exposure).

Methane hazard is one of the many occupational hazards, thus it is possible to apply by analogy to the equation (1) the

following measure of methane risk probability $p(M_R)$, which can occur in underground workings:

$$p(M_R) = p(M_I) p(L_{HM}) \quad (3)$$

where:

$p(M_I)$ – probability of ignition and/or explosion of methane,

$p(L_{HM})$ – probability of human and/or material losses, caused by the occurrence of ignition and/or methane explosion.

The form of risk indicator, by analogy to the formula (3) is:

$$M_{MR} = M_{MI} M_{HML} \quad (4)$$

where:

M_{MR} – the indicator of the magnitude of methane hazard estimation,

M_{MI} – indicator of ignition and/or methane explosion estimation,

M_{HML} – estimation indicator of human and/or material losses caused by methane-induced event.

The proposed, developed formula (4) to assess the magnitude of methane hazard M_{MR} in the area of the longwall, has the form:

$$M_{MR} = \underbrace{(M_{HF} + M_{MI} + M_{MP})}_{M_I} \underbrace{(M_{HL} + M_{ML})}_{M_{HML}} \quad (5)$$

where:

M_{HF} – indicator (magnitude) of impact assessment of causal factors of methane hazard in the vicinity of the longwall mining,

M_{MI} – indicator (magnitude) of the impact assessment of possible initiators of ignition and/or explosion of methane in the longwall mining area,

M_{MP} – indicator (magnitude) of the assessment of dangers detection of ignition and/or explosion taking into account the applicable methane prevention,

M_{HL} – indicator (magnitude) of the assessment of the magnitude of possible human losses due to ignition and/or explosion, taking into account the impact of the measures adopted in order to protect the crew,

M_{ML} – indicator (magnitude) of the possible material (property) losses as a result of ignition and/or explosion. It should be noted that the evaluation is not currently required by applicable laws.

The semantic interpretation of the components of the formula (5), are shown graphically in the diagram (Fig. 1).

A formation of methane hazard requires meeting the following conditions:

- Methane content in the air must reach the lower limit of ignition and/or explosion of methane.
- There must be an appropriate ignition initial, and appropriate oxygen content in the mixture of air and methane.
- The employee must be within the impact range of ignition energy and/or explosion of a mixture of air and methane.

The first two conditions are the mining, and geological and technical reasons for the risk of methane, defined as methane hazard. The third condition is the human factor, which could also be a personal cause of methane hazard as well as the personal effect of methane hazard. Another very important

condition affecting the size of the personal effects is the rate of workers' exposure to risk (M_E). It can be determined as the quotient of the time workers spend in danger zone to the normative (working) time.

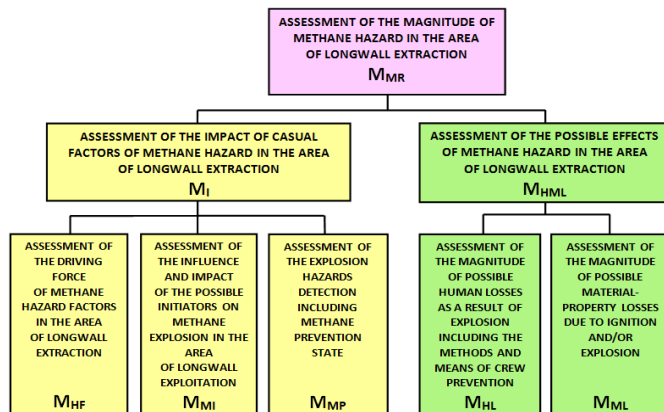


Fig. 1. Components of the magnitude of methane hazard assessment (own elaboration)

The personal and material effects of the risk are connected by economic category – loss, with its division into personal and material losses. Another issue, which does not fall within the scope of this paper are the punitive damages experienced by the victims and their families as well as social losses.

3. AN INTERACTIVE METHOD OF ASSESSING THE SIZE OF METHANE HAZARD IN THE AREA OF EXTRACTION – A PANEL OF EXPERTS

The paper proposes the heuristic methodology for the assessment of methane hazard, based on observing the facts and discovering dependencies and relationships between them, in order to study and predict new relationships and dependencies resulting from them. A similar approach applied to mining hazards is included in the papers (Krause & Łukowicz, 2001; Krzemień, 1990, 1991; Krzemień & Kowalik, 2000).

The heuristic methods include the Delphi techniques, which in many areas of application are accepted research tools. Delphi methodology was used for the first time at the end of World War II, among other things, to create scenarios of the impact and the development of military technologies that could be used in the future. Since then, these methods have been used, among others, to forecast the development of technology and to research economic trends and as a forecasting tool in business used to predict sales of new products and in many other applications. Currently, they are used also in the field of social research. The effectiveness and extent of the methods and Delphi techniques increased through the use of information technology.

To assess the magnitude of methane risk (MR) and a prediction of its changes, the SOPE – Survey of the Panel of Experts (Krzemień, 1990, 1991, 1992) method was applied. The tools used in this method are panels of experts and targeted surveys based on questionnaire techniques. The importance of the value of collective intelligence of an organized group of people called experts or judges is considered to be fundamental.

The Expert Panel (EP), is a repetitive interview with the participation of a group of specialists representing specific

areas of knowledge and practice carried out in order to capture on-going changes and assess the impact of the factors that cause them. When selecting the SOPE procedure to examine methane hazard in mines the following thesis was adopted: "in every methane bearing mine there is sufficiently numerous groups of employees who observe, implement, monitor and document the mining work carried out, including the extraction process, obtaining information on a current basis about disturbances and the level of the existing hazards, including information about the status of the methane hazard".

These people also have the knowledge and work experience that allow them to infer about the current state of the activity of methane hazard factors and take appropriate decisions and actions. Information on the emergency states of methane hazards and its possible accident consequences, possessed by experts (engineering-technical staff), is derived from measurements monitored by gas meter systems, anemometry systems and sensors of the status of equipment performance and direct observations made in underground workings. Additionally, these people obtain important qualitative information that reinforces their conclusions about the states and the level of methane hazard.

Indirect qualitative information is often obtained earlier by engineering-technical staff (experts) in the case of the occurrence of the events preceding the final and irreversible effects on the methane hazard. The phenomena preceding the events of catastrophic nature are called indications, symptoms, precursors or identifiers of hazardous events.

Symptoms of methane hazard are the situations being observed, phenomena or conditions whose occurrence and their course in mine working and its surroundings is a reasonable basis for the inference of the possibility of ignition and/or explosion of methane, as well as the creation of accident and health effects, including material losses.

Occurrence and the course of methane hazard symptoms is often random. The vast majority of directly measurable parameters and qualitative characteristics that describe them are changing over time in a stochastic manner, depending on the non-random time parameter "t", for instance, the presence of methane and changes in its concentration may be the evidence that in the close vicinity of measurements methane emission occurs from the surroundings as a result of mining-induced disturbance and, therefore, coal in the measuring points is cracked, affected by mining exploitation, and the recorded increases in methane indicate a potential methane hazard.

A temporary increase in the content of methane in mine air can be a symptom of such events as:

- emissions of methane from the post-exploitation goaf,
- disturbances in the ventilation network,
- changes in atmospheric pressure, etc.

The symptoms of methane hazard occur when the occurrence of certain phenomena takes place, events or processes such as:

- excessive amount of coal of strongly methane seam mined with a shearer,
- momentary ventilation failures – the occurrence of "ventilation blowout",

- increases of desorbing inflow of methane from coal as a result of the increased saturation,
- mining of rocks prone to sparks igniting methane,
- exceeding the threshold values of methane in the mine workings,
- damaging methane detection and automatic anemometry measuring instruments,
- failures of the methane drainage system,
- a start up of the longwall,
- ventilation and methane disturbance as a consequence of the seismic activity of the rock mass in the vicinity of workings,
- the unfavourable difference of aerodynamic potentials in the workings contouring goaf.

Identification of the symptoms of methane risk is an important source of knowledge and expert judgment. The processing of the experts' evaluations in SOPE-MR procedure facilitates the inference of the current state of methane risk.

Many experts, apart from indirect observations, have obtained direct data, often closely related to their professional activities and official duties performed. Generally, direct information is quantitative and it is derived from the registration of CH₄ by means of systems of automatic methane monitoring and methane measurements with individual devices.

Information registered on carriers allows for the creation of specialized databases that identify, to some extent, the current level of knowledge concerning methane risk. Databases and knowledge bases can be used on a regular basis and their continuous development and processing is a very important link in the modern management system in the mining industry. The aim of the system is to achieve an economically and socially acceptable level of methane risk in mines.

The method of group assessment by experts is described, among others (Krzemień, 1990, 1992; Krzemień & Kowalik, 2000), it includes a multistage procedure of assigning subjective assessments to dangerous incidents or their forerunners, by experts. The method includes the step procedure for determining the ratings of events with a request to identify the most likely and least likely event in the list (questionnaire), as well as detailing all the events in order of increasing probability. Then, the expert is asked to give his own assessment of the relative possibility of the occurrence of different incidents according to the adopted scale of values (weight) of these events. In the assessment classification by quality categories such as: likely, possible to occur, unlikely, rare, remote etc. are useful. The expert is also asked whether individual incidences presented in the list are more or less likely than some reference incidents.

Moreover, in the expert method the following are defined:

- indicators of the relative validity of assessment,
- the degree of experts' unanimity,
- the experts competency,
- the influence of time on the assessment of a particular incident.

Particular expertise on endangered facility includes a set of assessments expressed by each expert in their answer to the question in the questionnaire. These evaluations are expressed in an appropriate numerical scale, and using this we

can talk about the relative importance of features or their areas.

The degree of unanimity of the experts in relation to the relative importance of a set of ratings for examined workings determines the compatibility factor "Z" of Kendall and Babbington Smith (Krzemień, 1990, 1992). At the full unanimity of experts $Z = 1$. Changing Z from 0 to 1 corresponds with an increase in the degree of the experts' unanimity. Calculation of the degree of unanimity of experts' opinions enables the specification of groups of experts, within which consensus is high, and also reveals those experts which have original points of view that differ from the opinion of the majority.

In the procedure of group assessment by experts, their competences are assessed according to the formula:

$$K_k = \frac{K_z + K_a}{2} \quad (6)$$

where:

- K_k – indicator of experts' competence,
- K_z – factor determining the degree of knowledge by the expert assessing the problem,
- K_a – coefficient of argumentation.

Factor determining the degree of knowledge of the expert on the assessed problem and the coefficient of argumentation is determined for each expert. With this aim, one can use the tables given in the reference literature (Krzemień, 1991). The coefficient K_z is read from the table, wherein the degree of knowledge of the issues is expressed in points ranging from 0 to 10. The value read from the table K_z is multiplied by the value of 0.1. For example, if the assessed issue falls within the scope of expert specialization, as is the case when dealing with experts of engineering and the technical staff of a Ventilation Department, the value read from the table is 10, and after multiplying by 0.1, the coefficient value is $K_z = 1$.

Coefficient of argumentation K_a consists of three sources of argumentation:

1. Theoretical analysis – argumentation degree from 0.1 to 0.3.
2. Mining experience – argumentation degree from 0.2 to 0.5.
3. Intuition – argumentation degree 0.2.

In total, value $K_a = 1$, which corresponds to a high coefficient of argumentation.

After substituting the value $K_z = 1$ and the value of $K_a = 1$ into the equation (6) the indicator of competence of the experts involved in methane hazard assessment adopted the value $K_k = 1$. This is the maximum value of the indicator K_k , which is justified, inter alia, with the fact that:

- these persons are organizationally and functionally related to the assessed mine workings and methane hazard occurring within them
- they have a great amount of work experience in the area of methane occurrence
- they are highly qualified, took specialized training in the field of ventilation, fires and prevention in the fight against methane hazard
- they are able to correctly apply the criteria for assessing the methane hazard
- they have professional experience and sharpened mining intuition.

4. METHANE HAZARD ASSESSMENT OF THE ENVIRONMENT OF LONGWALLS EXPLOITED IN THE "A-Z" MINE

Presented in this paper, studies of the size of methane hazard with the use of SOPE method were conducted in the "A-Z" methane bearing coal mine. The "A-Z" mine is a two-way mine consisting of mining operations "A" and "Z".

The risk assessment procedure consisted of the following steps:

- The identification of objects experiencing methane risk assessment.
- The identification of the problem areas of methane hazard.
- The preparation of a Methane Risk Assessment Questionnaire.
- The appointment of a representative group of experts.
- Conducting surveys.
- Using the results of evaluations – development of methane risk matrix.
- The calculation of methane risk indicators for the exploitation regions.
- Determining the criteria of the methane risk acceptance level and assigning facilities to the appropriate risk category and consequences of loss.

The object of the study included five regions of longwalls, two longwalls operated towards the direction of "A" and three towards the "Z" direction. The study included the longwalls: a, b, c, x, y, and it was carried out in 2013.

To assess each area of the mine, a Methane Risk Assessment Questionnaire was used, consisting of four cards. Each card contains one of the areas of the risk factors shown in Figure 1 and in the formula (5), i.e.:

Card I. State of factors shaping methane hazard HF (17 factors)

Card II. The activity of methane ignition initiators MI (19 factors)

Card III. The detection and prevention of methane hazard MP (16 factors)

Card IV. Possible human and material losses HML (13 factors).

Important sources of identification of methane risk factors assessed in the questionnaire were, among others, the documentation provided by the committees appointed by the President of the State Mining Authority to investigate the causes and circumstances of methane inflammation and the collective consequences of such accidents, and the expertise of scientific institutions, as well as documentation specifying the conditions for the safe performance of mining activities in methane hazard conditions.

Rules for the selection of the panel of experts are described in Section 3 of the paper. The panel of experts chosen to assess the methane hazard in the exploitation region of the mine area has been designated on the basis of the Polish standard for risk assessment (PN-N-18002, 2011) recommending that the team assessing every professional hazard consisted of persons who:

- know and understand the principles of risk assessment
- have the knowledge necessary to identify hazards in the place of their occurrence
- are able to assess the effects of hazards in the workplace.

In the studies, the following indicators were used: an indicator of expert competence, an indicator of methane hazard knowledge in the longwalls and an indicator of argumentation. For a panel of experts evaluating the risk, 35 mine workers of the "A-Z" mine were identified. They were the chief ventilation engineers, ventilation engineers, mining supervisors for ventilation, supervisors for mining exploitation, foremen for extraction and measuring personnel.

The experts completed a total of 46 sets of questionnaires; in addition, some experts were surveyed for the two areas of longwall in relation to the scope of their duties including two extraction areas.

Each of the experts evaluated 65 factors influencing the causes and consequences of methane risk in the exploitation region. An expert could allot each of the assessed factors the value of the assessment in a 3-point scale, adopted as follows:

$$C_{ij} = \begin{cases} 1 - \text{small influence of risk factor} \\ 2 - \text{average influence of risk factor} \\ 3 - \text{high influence of risk factor} \end{cases} \quad (7)$$

where C_{ij} – represents the relative value of the assessment expressed by " i^{th} " – expert for " j^{th} " – evaluated factor of methane risk.

Indicators of methane risk assessments of problem areas M_{HF} , M_{MI} , M_{MP} and M_{HML} were calculated according to the formula (8)

$$\left. \begin{matrix} M_{HF} \\ M_{MI} \\ M_{MP} \\ M_{HML} \end{matrix} \right\} = \frac{3C_3 + 2C_2 + C_1}{ij} \quad (8)$$

where:

C_3 – number of answers with mark 3,

C_2 – number of answers with mark 2,

C_1 – number of answers with mark 1,

j – number of the assessed hazard indicators of the problem risk area,

i – number of experts taking part in the assessment of the problem risk area.

Aggregated indicators of methane risk assessment for each region of longwall exploitation in "A-Z" mine were calculated from formula (5) presented in the form of:

$$M_{MR} = (M_{HF} + M_{MI} + M_{PM}) M_{HML} \quad (9)$$

A summary of the results of the methane risk assessments for the areas of longwall extraction in the "A-Z" mine and their comparison in terms of rating is shown in Table 1.

Table 1. Summary of the results of methane risk assessment for the longwall areas of mine "A-Z"

Risk indicator of problem area	Name of the problem area of methane hazard	Area of longwalls of "A-Z" hard coal mine				
		a	b	c	x	y
M_{HF}	State of methane hazard factors	1.576	1.935	1.455	1.985	1.698
M_{MI}	Activity of methane ignition initiators	1.489	1.431	1.427	1.816	1.691
M_{MP}	The detection and prevention of methane hazard	1.306	1.212	1.101	1.640	1.929
M_{HML}	Possible human and material losses	2.007	2.038	2.018	1.663	1.730
M_{MR}	Indicator of methane hazard assessment	8.772	9.329	8.038	9.048	9.201
	Comparison of indicators of methane hazard assessments – ranking of the risk of longwall areas	IV	I	V	III	II

Methane risk acceptance criteria for the longwall working area are shown in Table 2. These are the preliminary criteria resulting from the findings adopted by the expert panel. Their final form will be verified in the course of further studies.

Table 2. Acceptability criteria of methane risk of the longwall region in the SOPE method

Level of methane risk of longwall area	M_{MR} Indicator of methane risk assessment of longwall area	M_{HML} Indicator of risk assessment losses – necessary condition	Consequence grade of losses risk in the area of longwall	Grade symbol
R1 Unacceptable risk	above 13.5	–	Area particularly dangerous	K1SN
R2 Tolerable risk (conditional)	above 9 up to 13.5	–	Dangerous area	K2N
R3 Acceptable risk	up to 9	up to 2	Area almost dangerous	K3PB

The highest assessment of methane risk and the first place in the rankings was given to the area of longwall b. The methane risk indicator M_{MR} of this region was 9.329, which represents about 35% of the theoretical value of the maximum risk ($M_{MRmax} = 27$). Table 2 shows that this value corresponds to the level of risk R2, i.e. tolerable risk and the grade of consequences of a loss of K2N.

This means that the longwall b area should be regarded as a hazardous area of methane risk. This conclusion is further confirmed by the indicator M_{HML} outlining the possible consequences of risk in the form of human and material losses. Looking at Table 1 for the area of longwall b, the value of the indicator of loss risk assessment $M_{HML} = 2.038$ is 68% which is theoretically the possible maximum value of this indicator ($M_{HMLmax} = 3$). The value $M_{HML} = 2.038$ is the highest among similar values assigned to other parts of the "A-Z" MINE. The decisive factor here was the assessment of the relevance of the impact of the following factors on the magnitude of the risk:

- high number of people occupying the longwall area at the same time (80% of rating)
- being equipped with emergency respiratory protection equipment (60% of rating)
- control of the presence of persons and the time they stayed in methane risk zones (60% of rating)
- assessment of the means of communication and notification (50% of rating)
- the status of head protection against physical injury (50% of rating), and
- the status of emergency switches and ventilation protection (50% rating).

The analysis of the results in the next three assessed areas of methane risk factors for the area of longwall b is as follows:

- Area HF: "State of methane risk factors". According to experts, the biggest impact on the size of the risk indicator in the vicinity of the longwalls where, among others, such factors are:
 - the impact of methane drainage,
 - the impact of other electrical equipment,
 - the impact of the longwall advance,
 - the impact of work organization,
 - the impact of ventilation conditions.

The value of risk indicator in this area $M_{HF} = 1.455$ is the lowest value against the values of M_{HF} of the other assessed

areas, which may indicate a satisfying technical prevention against methane hazard in this region.

- Area MI: "The activity of methane ignition initiators". According to experts, the most profound impact on the size of the risk indicator in the vicinity of the longwalls had, among others, such factors as:
 - the possibility of fire,
 - the impact of the possibility of local explosive mixture formation,
 - failure to comply with procedures for work performance in methane hazard areas,
 - the likelihood of sparking from electrical devices,
 - failure to comply with procedures for work performance in methane hazard areas,
 - disturbances of ventilation,
 - incorrect built-in methane devices.

The risk index value of this area was $M_{MI} = 1.431$ which in the ranking of areas places it on the penultimate (fourth) place and according to experts indicates relatively low activity of the factors of initial methane ignition.

- Area MP: "The detection and prevention of the methane risk". According to experts, the most significant impact on the size of the risk index in the vicinity of the longwalls had, among others, such factors as:
 - the frequency of de-energizing electrical equipment,
 - lack of access to current information about the methane risk,
 - the level of safety culture of employees hired in the evaluated area of the longwall,
 - the tendency of workers towards risk behaviour,
 - the possession of means to initiate ignition.

Risk index value of this area was $M_{PM} = 1.212$ which in the risk scale is of a relatively low value (fourth place in the ranking). It may indicate the good detection and appropriate methane risk prevention in the assessed longwall region.

The presented example of methane risk assessment relates to the area of longwall b. Similar analyses were performed for the remaining longwalls of the mine "A-Z". The risk assessment in the area of longwall c is noteworthy. This region in the ranking (Table 1) obtained the lowest and best indicator of the methane risk assessment $M_{MR} = 8.038$, which indicates the effectiveness of methane prevention risk in this region of longwall mining.

Looking at the results of the presented survey of methane hazard involving engineering-technical staff of the "A-Z" methane bearing mine, including five exploited longwalls, it can be concluded that:

- the levels of methane hazard in all the surveyed areas of longwall mining fall within a tolerable risk category,
- methane risk indicators M_{MRi} of all longwall areas covered by the study are in the range of 8.038 to 9.329, with the limit values of tolerable risk range from 9 to 13.5,
- indicators of the consequences of human and material losses M_{HML} for the two longwall regions, i.e. region x and region y reached a value less than 2 – consequently classing the K3PB – area almost safe; nevertheless, these regions, like the other three, have been classified as hazardous areas K2N; the values of indicators M_{HF} , M_{MI} and M_{MP} – tolerable risk and conditional R2 were decisive here.

Methane risk levels in the exploited 5 longwalls in the "A-Z" mine, probably do not differ from the methane risk level of longwalls exploited in other Polish mines in the seams included in II, III and IV category of methane hazard – however this requires broader study.

5. CONCLUSIONS

The presented method of the methane risk assessment of the longwall areas of mines, SOPE based on a heuristic model of the group survey of experts' opinions, does not replace the previously used and effective methods of methane hazard assessment. However, it may constitute an important element of inference about the state of risk, inter alia, on the basis of efficient computer processing of information from the observation of phenomena preceding the symptoms of dangerous events. The obtained evaluations show that the SOPE method can be used in methane risk management procedures, especially at the stage of analysis and assessment of causes of methane risk and at the stage of the possibility of predicting the effects of an accident. The method procedures can be applied in the designing and construction of information systems of safety (KSIB) in mines.

The obtained results of risk assessments and analysis of their changes should be used to inform and alert the crew about the current state of methane risk and used to develop active strategies to respond to crisis situations. SOPE method allows us to observe and control the magnitude of methane risk in accordance with the established criteria for the level of risk, and enables us to take action to minimize its consequences. Mutual comparison of the magnitude of the methane risk of longwalls gives an order of the technical and organizational prevention of methane hazard in the mine.

An important advantage of the SOPE method is the large and active participation of engineering-technical personnel of the mine. Enabling groups of employees to join such activities, called the principle of participation, is one of the basic conditions for effective improvement of safety as defined in the Directive 89/391/EU.

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