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OPTICAL METHOD FOR CONTINUOUS MONITORING OF DUST DEPOSITION IN MINE'S ENTRY

OPTYCZNA METODA CIĄGŁEGO POMIARU INTENSYWNOŚCI OSIADANIA PYŁU WĘGLOWEGO W WYROBISKU GÓRNICZYM

The paper presents factors determining dust explosion hazards occurring in underground hard coal mines. The authors described the mechanism of transport and deposition of dust in mines entries and previous research on this topic.

The paper presents a method of determination of depositing dust distribution during mining and presents the way to use it to assess coal dust explosion risk. The presented method of calculating the intensity of coal dust deposition is based on continuous monitoring of coal dust concentrations with use of optical sensors. Mathematical model of the distribution of the average coal dust concentration was created. Presented method allows to calculate the intensity of coal dust deposition in a continuous manner.

Additionally, the authors presented the PŁ-2 stationary optical dust sampler, used in the study, connected to the monitoring system in the mine. The article features the results of studies conducted in the return air courses of the active longwalls, and the results of calculations of dust deposition intensity carried out with the use of the presented method.

Keywords: coal dust concentration, deposited dust, explosion hazard, dust sampler, model

W artykule scharakteryzowane zostały czynniki wpływające na ryzyko wybuchu pyłu węglowego. Opisany został mechanizm transportu i osiadania pyłu w wyrobiskach kopalnianych oraz badania innych naukowców zajmujących się tą tematyką.

Przedstawiono sposób wyznaczania rozkładów ilości osiadłego pyłu węglowego powstającego podczas eksploatacji węgla i sposób wykorzystania tych rozkładów do oceny ryzyka wybuchu pyłu węglowego. Przedstawiona metoda obliczania intensywności osiadania pyłu węglowego bazuje na ciągłych pomiarach stężenia pyłu w powietrzu wentylacyjnym czujnikami optycznymi oraz matematycznym modelu rozkładu średniego stężenia pyłu. Zaprezentowana metoda pozwala na obliczanie intensywności osiadania pyłu węglowego w sposób ciągły.

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Przedstawiono, wykorzystany w badaniach, stacjonarny pyłomierz optyczny PŁ-2 i system pomiarowy kopalni. W artykule zamieszone zostały wyniki badań przeprowadzonych w wyrobiskach nadścianowych czynnych ścian wydobywczych i wyniki obliczeń intensywności osiadania pyłu przeprowadzone przy użyciu zaprezentowanej metody.

Słowa kluczowe: stężenie pyłu węglowego, pył osiadły, zagrożenie wybuchem, pyłomierz, model

1. Introduction

By the end of 2010 the world hard coal output amounted to 7,273.3 million tonnes (bp.com/statisticalreview). The number of people employed directly in mining operations is about 4 million. These people are potentially exposed to coal dust explosions. As previous coal dust explosions show, such events have the most tragic consequences. Contrary to other hazards, caused by methane, fire or water, coal dust explosion hazards are present in every underground hard coal mine. The major stimulus for a coal dust explosion is ignition or a methane explosion. Methane explosions, however, have a local character in a mine and do not cover many mine workings. Local explosions occur due to the impossibility to keep methane concentration in the range between 5-15% in the ventilation air. Whereas coal dust generated during mining operations is omnipresent and carried by the ventilation air on long distances.

Though the coal dust explosion hazard is one of the most tragic in terms of its consequences, it has not been continuously monitored so far and its assessment has been based on periodical drawing of samples from certain spots and then their analysis in a laboratory. No sooner than the laboratory results are available, is it possible to identify areas with deposited dust explosion hazards and to set the time for stone dusting or rinsing off with water, which are basic preventive measures to eliminate the hazard. The last protection against the coal dust explosion is to use anti-explosion water or dust dams whose task is to suppress the explosion that has already occurred. Although their suppressing efficiency is high, the dams do not provide protection in the areas between the place where the explosion initiates and the dam itself, and the number of employees is the biggest in these areas.

Due to the diversity of dust sources and the dynamic character of its expansion in mine workings, full assessment of hazards resulting from coal dust occurrence, particularly the assessment of deposited dust explosion hazards, can be carried out only on the basis of continuous measurements. This can be achieved by the PŁ-2 stationary optical dust sampler, developed in the Institute of Innovative Technologies EMAG. The counter is adapted to work with measurement systems used in mines and allows continuous monitoring of air dustiness in a given area.

Currently used manual devices for measuring dustiness allow only random or periodical measurements. These are, for example, isokinetic dust samplers which make cumulative measurements in a certain period of time and calculate average dustiness for the respirable or total fraction, in compliance with a valid standard. Whereas for the measurement of instantaneous and maximal values of dustiness, manual optical dust samplers are occasionally used. They measure the dustiness of the respirable fraction. Such research does not allow to get a full analysis of time characteristics of dustiness, the efficiency of de-dusting systems, and the distribution of air dustiness and deposited dust on the walls and floor of the mine working. Contrary to other hazards occurring in coal mines, such as methane or fire hazards, the coal dust hazards have not been subject of continuous monitoring so far. The signals registered by the optical dust sampler provide new possibilities and allow to have a more extensive analysis of the hazard caused by the occurrence of coal dust, particularly thanks to the possibility to calculate parameters which influence on the dust explosion hazard. Additionally, the analysis of the registered courses allows continuous monitoring of spraying and de-dusting devices (if such devices are used).

The paper presents a method to determine the models of average distribution of respirable and deposited dust in mine workings on the basis of continuous measurements of dust concentration carried out with the use of sensors placed along the mine working. The distribution values achieved in this way are the basis to assess the risk of the deposited dust explosion.

The paper contains the test results achieved during the execution of a reseach project No N524359838 financed by the Ministry of Science and Higher Education.

2. Factors influencing coal dust explosion risk

The coal dust explosion is a complex process. The risk of the coal dust explosion is influenced by many factors, such as:

- type and intensity of dust sources,
- dust's size distribution
- combustible properties of dust,
- explosive limits,
- explosion initials,
- dust concentration and distribution of deposited dust in mine workings,
- methane presence in the air,
- size of mine workings.

The assessment of coal dust explosion risk should begin with the analysis of particular elements that make up the so called explosion pentagon (Małachowski, Mróz et. al., 2011). The explosion will happen when five characteristic elements occur at the same time, which is illustrated in Fig. 1.

Breaking the connections between these elements or lack of one element will enable the explosion. As far as coal dust is concerned, particular elements can be characterized in the following way:

- fuel – deposited coal dust with different size distribution, generated during a mining operation, transported with the ventilation air on long distances and deposited along its way,

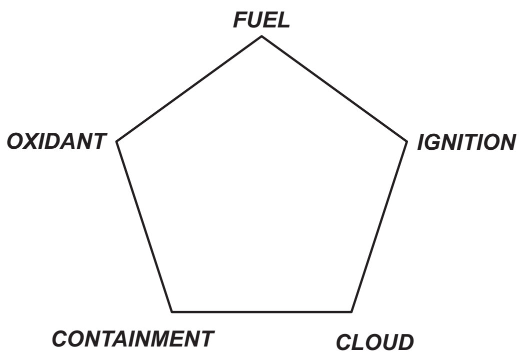

Fig. 1. Explosion pentagon

- oxidant – (atmospheric) oxygen in the ventilation air,
- cloud – deposited coal dust itself is not dangerous, it becomes dangerous once it gets mixed with the air, i.e. oxidant, this way a dust cloud is formed,
- ignition – main ignition initials are ignition or an explosion of methane, as well as blasting works and, less frequently, electric arc,
- containment – space naturally formed by mine workings.

There are two elements of the explosion pentagon that have the most influence on minimizing the risk of the coal dust explosion: ignition initials (ignition) and fuel. The regulations concerning the methane hazard and its monitoring as well as regulations about safe use of explosion materials provide protection in the case of the coal dust explosion, provided that they are followed. The use of automatic methane monitoring and conducting blasting works in compliance with security regulations allow to have enough control over this element. The second element is fuel which has the biggest impact on the explosion risk. Total elimination of this element is not possible. The dust generated in the process of coal mining is inevitable and omnipresent. The only influence we have on it is to limit its generation as well as to remove or neutralize its remaining part. The other elements of the pentagon, such as the oxidant, cloud and closed space are and will be present always. They cannot be eliminated with a view to lower the explosion risk.

3. Parameters to assess coal dust explosion risk

In order to assess the coal dust explosion risk there are two parameters used which determine the volume of dust in the mine working. The first parameter is the volume of airborne respirable dust in the air (dust concentration) expressed in mass unit per volume (mg/m^3). The term of airborne respirable dust in the air (dust particles in gas) suggests a description of a static state which, however, is not in accordance with reality. The deposited dust in the air is subject to constant moves, starting from the Brownian movement (small particles) to the movement caused by the ventilation air passing through the mine working.

The second parameter is the intensity of dust depositing in the mine working (deposited dust) expressed in mass unit per area per time (g/m^2/24h). This is the dust precipitated from the gas phase as a result of such phenomena as elutriation, impact and gravitation (Lebecki, 2004). The dust depositing intensity or, in other words, the volume of the deposited dust depends on:

- intensity of the dust source,
- size distribution of dust particles,
- velocity of the air flowing through the mine working, shape and size of the mine working, and the occurrence of possible barriers in the airway.

4. Dust transport and deposition in mine entries

While studying the literature on the topic, some theoretical and experimental research results were found on the dust behaviour in the flowing air. Most of this research, due to the lack of proper measurement methods, was done on the basis of theoretical and statistical data (Bradshaw et al., 1954; Hamilton & Walton, 1961; Courtney et al., 1982; Pereles, 1958). The first experimental data were gathered by Dawes and Slack (1954) who, on this basis, elaborated an elementary model describing the behaviour of a dust particle in the flowing air. The measurement data of Dawes and Slack's research (1954) were used by other researchers to validate the models they proposed. Additionally, the research on elaborating a mathematical model that would allow to predict dust concentration and determine the volume of deposited dust was conducted by scientists involved in the flow of aerosols. This research aimed at elaborating a better, more representative model. The developed models, depending on their degree of complexity, took into account the following mechanisms that had impact on a dust particle:

- dispersion,
- coagulation,
- diffusion,
- Brownian movement,
- electrostatics,
- thermal motion,
- impact of the turbulent character of the air flow,
- impact of gravitation,
- sedimentation.

The attempts to make a mathematical model describing the behaviour of dust particles in the flowing air aimed at explaining and understanding the phenomena which occurred during dust transport in the air. The diversity of parameters in models, different degrees of detail and the lack of proper measurement methods result in poor effects of using these models for continuous assessment of the coal dust explosion hazard. A common feature of all above described models is the exponential character of dustiness distribution which will be confirmed by test results presented further in this paper.

To sum up the issue, it is justifiable to say that in spite of good theoretical recognition of the dust depositing phenomenon and dust behaviour in the flowing air, there have not been practical solutions so far enabling to continuously assess the dust explosion hazards.

5. Method description

The concept of the method to assess the coal dust explosion risk emerged on the basis of continuous measurement of the respirable dust concentration in the ventilation air, and the research on how the concentration values are formed along the way of dust transport with the ventilation air from the place where the dust is generated. The preliminary tests made with optical dust samplers showed that the concentration of respirable dust decreases proportionally to the increasing distance from the dust source in the exponential manner and it is possible to determine, on their basis, a mathematical model of the average distribution of dust concentration in the mine working. On the basis of the average distribution of respirable dust concentration it is possible to determine the average distribution of dust loss which gives information about the volume of the dust deposited along its way of transport with the ventilation air. Analyzing this model with respect to the assessment of the coal dust explosion risk, it is necessary to introduce a conversion factor between the measured respirable fraction and total fraction, i.e. the fraction of coal dust particles which are the most vulnerable to explosions. Then, on the basis of the determined model of the average loss of the total dust concentration and with the help of proper software, it is possible to calculate, in a continuous manner, the intensity of coal dust depositing.

As it was mentioned before, the basis to assess the coal dust explosion risk is the mathematical model of the average distribution of airborne respirable dust in the ventilation air of the tested mine working (Mróz & Małachowski, 2009). This model is determined based on the measurements of dust concentration made with the use of at least three PŁ-2 stationary optical dust samplers which are placed along the tested mine working. A sample distribution of dust samplers can be seen in Fig. 2.

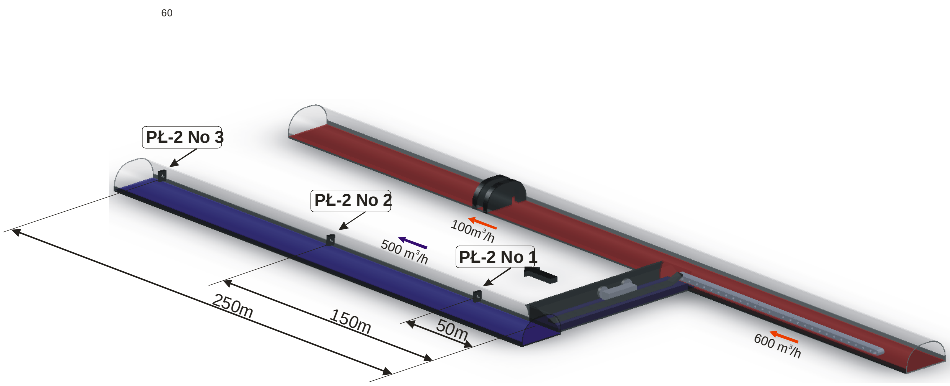

Fig. 2. Distribution of PŁ-2 dust samplers in the tested mine working

For all calculations there was a distance of 300 m assumed from the dust source (outlet from the face). This corresponds to the length of the protection zone (200 m) resulting from valid regulations on the dust explosion hazard, increased by 50%. The location of dust samplers in the tested area of the mine working should be the following: the first sensor should be placed as close as possible to the outlet, the second roughly in the middle of the zone, while the third at the end of the zone. Such distribution of sensors enables to observe the changes in the dust concentration occuring along with the increasing distance from the dust source which is, in this case, the combination of the working cutter loader, movements of the support, coal delivery from the chain conveyor to the belt conveyor, and the crusher. Sample courses from three dust countres registered during the tests are presented in Fig. 3.

Based on the presented measurement results, it is possible to observe the changes in signal amplitudes of particular dust samplers – the amplitudes decrease proportionally to the increasing distance from the dust source, and the time shift between them caused by the movement of the flowing ventilation air. The change (decrease) of the signal amplitudes with the increasing distance from the dust source shows that a part of the dust gets precipitated from the air and is deposited in the mine working. By analyzing the signals registered this way, it is possible to determine the average distribution of dust concentration in the mine working which characterizes the dust behaviour in the ventilation air flowing through the mine working.

In order to determine the dust distribution function and its parameters, the registered courses of instantaneous values of dustiness are analyzed, which means that the average values of dustiness are determined in a longer period of time (min. 8 hours) for each of the three dust samplers. After the average values are determined and then mapped on the length axis in accordance with

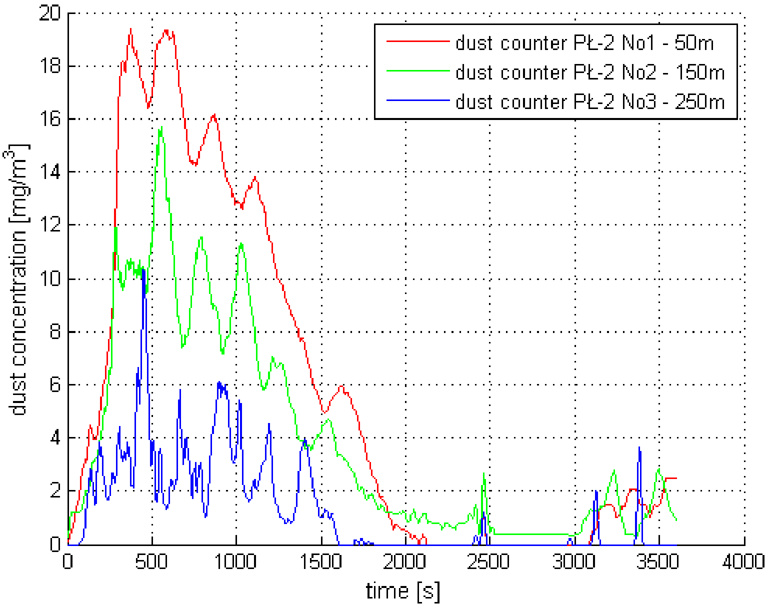

Fig. 3. Dust concentration registered by PŁ-2 dust samplers successively
in the distance of 10, 50 and 100 meters

the distances of their locations in the mine working, it is possible to interpolate the envelope line of the average distribution of airborne respirable dust in the air. The approximate line determined in this manner is an exponential function in the following form:

$$C(x) = A_o \cdot e^{-bx} \tag{1}$$

where:

- A_o — average dust concentration close to the dust source [mg/m³],
- b — quality coefficient of dust depositing [1/m],
- x — distance, length of the tested mine working [m].

Putting the above equation into a vector form, it is possible to determine numerically the average distribution of dust concentration in a given section of the mine working.

$$\vec{C} = A_o \cdot e^{-b\vec{x}} \tag{2}$$

The components of vector x are successive distances from the dust source for which average concentration values are determined. A sample distribution of dust concentration in the mine working is presented in Fig. 4.

The result vector C is the vector of the distribution of dust concentration along the determined length which is the basis to determine the distribution of the concentration loss $C_U(x)$. In Fig. 5 below there are sample courses of average distributions of dust concentration for the periods of 8, 16 and 24 hours.

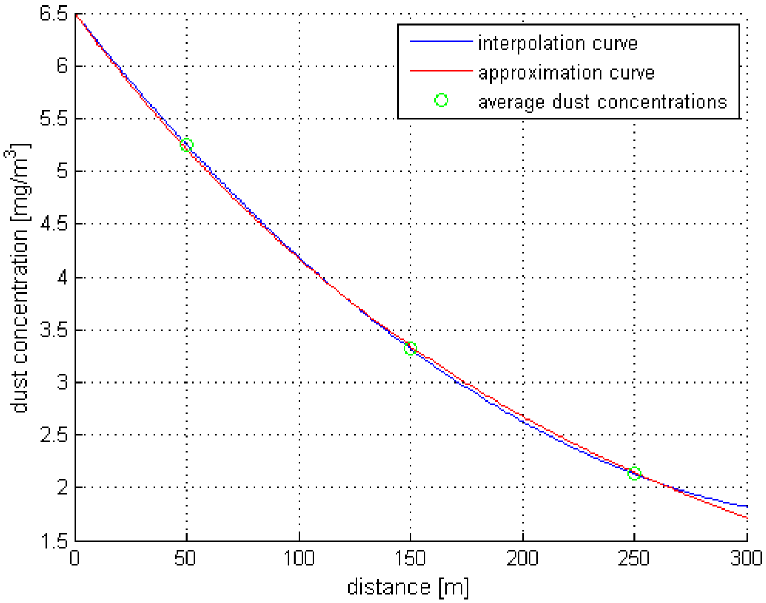

Fig. 4. Distribution of average dust concentration in the mine working

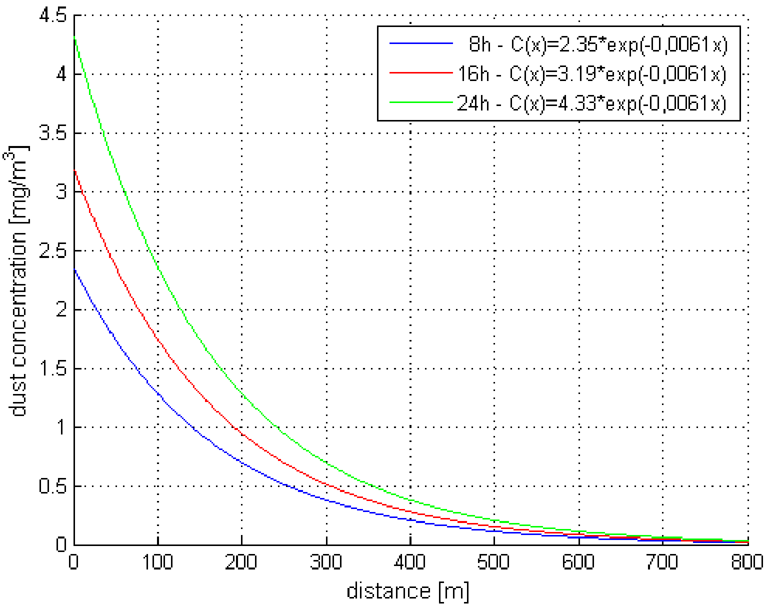

Fig. 5. Average distribution of dust concentration in the mine working

The average distribution of dust concentration is determined in order to calculate the value of the dust depositing quality coefficient b. The next step is to determine the average distribution of dust concentration loss $C_U(x)$. This distribution gives information on the volume of loss in the airborne respirable dust concentration which occurs as the distance from the dustiness source increases. The function of the average distribution of loss was presented in Fig. 6 and has the following form:

$$C_U(x) = C(x) \cdot \frac{A_{śr}(x_1) - A_{śr}(x_2)}{A_{śr}(x_1)} = C(x) \cdot k \tag{3}$$

where:

k — quantity coefficient of dust depositing (non-dimensional),

$x_1 - x_2 = 1$ m.

The b and k coefficients determine the slope of the distribution curve and depend on the velocity of the ventilation air flow in the tested mine working and on the intensity of the dustiness source.

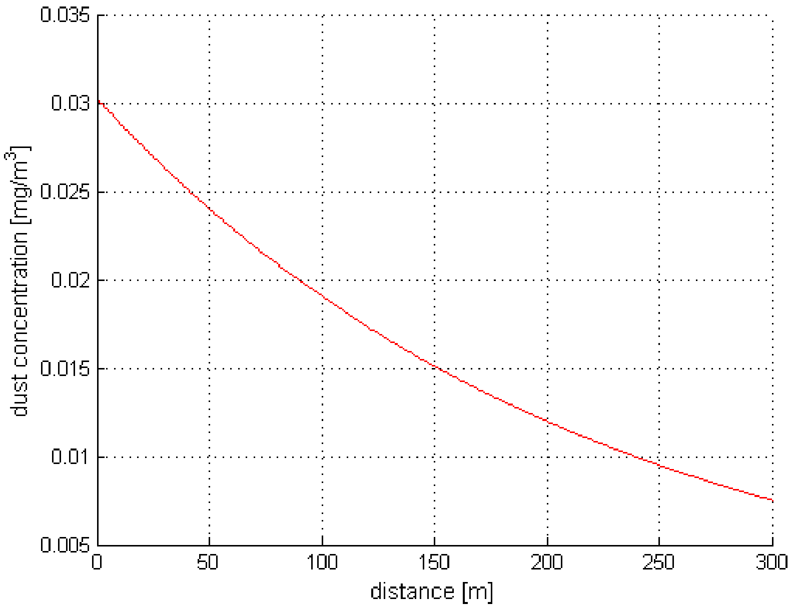

Fig. 6. Average distribution of dust concentration loss in the mine working

The above listed distributions are based on average values of air dustiness and serve to calculate the values of the b and k coefficients which, in the later stage, will be used to calculate the mass of deposited dust. For better (full) illustration of the dustiness distribution, the $C_U(x)$ function can be made dependant on time and the instantaneous values of the concentration can be used for the calculations. In this case the distribution function of the concentration loss in the mine working has the following form:

$$C_U(x,t) = A(t) \cdot k \cdot e^{-bx} \tag{4}$$

where: $C(x,t)$ — is the value of the dust concentration loss, calculated in a given moment in the selected distance from the measuring point, while $A(t)$ is the instantaneous value of dust concentration.

By putting the equation (4) in the matrix form, it is possible to determine the spatial distribution of the dust concentration loss in a given section and in a given period of time.

$$\overrightarrow{C_U} = \vec{A}(t) \cdot e^{-b\vec{x}} \tag{5}$$

Solving this equation, we get the matrix of the dust concentration loss C_U with the dimensions m (number of the distance vector components) per n (number of the components of the dust concentration loss vector in a measuring point in a given time). A sample spatial distribution of dust concentration loss in the mining mine working is presented in Fig. 7.

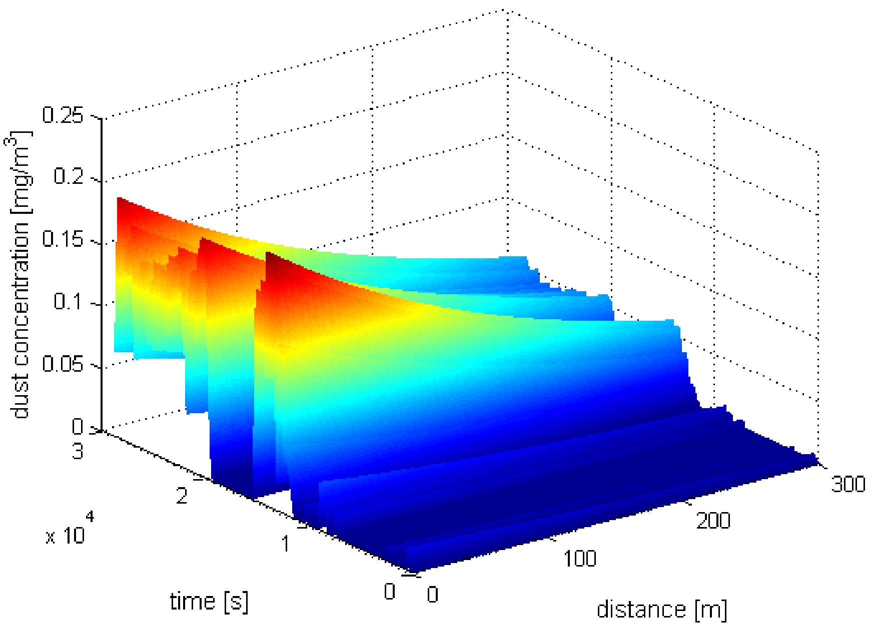

Fig. 7. Spatial distribution of dust concentration loss

In order to assess the deposited dust explosion hazard on the basis of the above distribution functions and the measurements of instantaneous values of dust concentration, it is necessary to have one more coefficient which takes into account the dependency between the contents of the dust total fraction and the respirable fraction measured by PŁ-2 optical dust samplers. This dependency can be determined by means of two methods. The first one is based on determining the ratio of the total dust value (measured by an isokinetic dust sampler) in a given period of time to the average value of dust concentration registered by a PŁ-2 dust sampler in the same period of time.

$$z = \frac{A_{total}}{A_{av\_opt}} \tag{6}$$

where:

A_{total} — the value of dust concentration measured by an isokinetic dust sampler for the total fraction,

A_{av_opt} — the average value of dust concentration measured by an optical dust sampler.

The second method is based on the size analysis of deposited dust particles sampled from the floor and wall along the tested mine working (e.g. in places where sensors are installed). This is also the ratio of the total fraction contents to the respirable fraction contents. For the obtained data, the conversion factor z'_{120} is calculated for the total fraction measured by an isokinetic dust sampler and, additionally, the z'_{200} factor for the total dust fraction with respect to the grains with the highest explosion vulnerability. For particular fractions, the following size ranges of particles are assumed:

- respirable fraction: 0÷12 µm (≈ 1250 mesh*),
- total fraction measured by a CPI-10-I dust sampler: 0÷120 µm (≈ 120 mesh),
- total fraction with respect to the dust with the highest explosion vulnerability: 0÷75 µm (200 mesh).

Both methods of determining the proportion coefficient between the total fraction and the respirable fraction give measurable effects, yet the second method, though more laborious, gives more precise results.

Having determined the distribution model of the dust concentration loss along with its parameters, it is possible to analyze it with respect to the coal dust explosion risk assessment. By replacing in the model the instantaneous values of dust concentration registered by a dust sampler placed near the dustiness source, it is possible to calculate the intensity of total coal dust depositing along the mine working, expressed in mass unit per area per time. The calculations are based on integrating the distributions of concentration loss for the registered instantaneous values with respect to the distance, and then by summing them up in time. This is done with the help of the following function:

$$\begin{aligned} M_o &= \sum_{t=0}^{t} \left[\int_{x_1}^{x_2} (C_U(x,t) \cdot z) dx \right] = \sum_{t=0}^{t} \left[\int_{x_1}^{x_2} (A(t) \cdot z \cdot k \cdot e^{-bx}) dx \right] = \\ &= \sum_{t=0}^{t} \left[z \cdot k \cdot A(t) \int_{x_1}^{x_2} e^{-bx} dx \right] = \sum_{t=0}^{t} \left[-\frac{z \cdot k \cdot A(t)}{b} (e^{-bx_2} - e^{-bx_1}) \right] \end{aligned} \tag{7}$$

* 120 mesh = 120 meshes per square inch

where:

$A(t)$ — instantaneous value of dust concentration [mg/m^3],

z — factor which takes into account the dependency between the contents of the dust total fraction and the respirable fraction (non-dimensional),

k — quantity coefficient of dust depositing (non-dimensional),

b — quality coefficient of dust depositing [1/m],

x — distance [m].

The following were assumed for the calculations:

- dust samplers measure the concentration of clean coal dust in mass unit per volume [mg/m^3],
- limits of integration:
  x_1 – beginning of the mine working (intersection of the face end and the top road),
  x_2 – end of the analyzed section of the mine working: 300 m,
- measuring time: 8-hour measuring series were carried out.

The calculations were carried out by means of the Matlab software with the use of which a script was written to perform the following functions:

- loading measurement data from three dust samplers,
- filtering the registered courses with the 7 elements moving average,
- calculating average values for each course,
- determining the distribution of dust concentration in the mine working (spline interpolation method and exponential function approximation),
- calculating the parameters of the distribution model of dust concentration in the mine working (A_o, b, k),
- generating diagrams of instantaneous values of dust concentration registered by dust samplers,
- generating a distribution diagram of dust concentration in the mine working,
- calculating the distribution of dust concentration loss,
- generating a spatial diagram of the distribution of average dust concentration in the mine working,
- generating a spatial diagram of the distribution of dust concentration loss in the mine working,
- calculating the intensity of coal dust depositing in the tested mine working.

6. Testing process

While the tests were conducted in a mine, there were instantaneous values of coal dust concentration registered in the top roads of two working faces. The tests were carried out at three methods of the face area ventilation. In total, there were measurements registered from 18 days with the mining operations going on almost without any disturbances. Each registered twenty-four-hour course of coal dust concentration was divided into three eight-hour periods and for each of these periods the following were elaborated: a model of average distribution of dust concentration, spatial distribution of dust concentration, spatial distribution of dust concentration loss, and the intensity of dust depositing was determined on the basis of dependencies presented in the method description.

The basic device used during the test was the PŁ-2/50 stationary optical dust sampler elaborated in the EMAG Institute, presented in Fig. 8.

Fig. 8. PŁ-2 stationary optical dust sampler (ITI EMAG)

PŁ-2 is an optical device working on the basis of the phenomenon of light scattering by dust particles (Mróz & Małachowski et al., 2008). Its operating principle is based on the so called Tyndall effect, i.e. light scattering by particles in a colloid (wikipedia.org, 2011), here being a mixture of coal dust and air.

The PŁ-2 dust sampler makes it possible to have continuous measurement and registration of respirable dust concentration (dust particles diameter up to about 8 μm) in the range of 0÷100 mg/m³ (PŁ-2/100 version) or 0÷50 mg/m³ (PŁ-2/50 version), which is related to proper calibration of the dust sampler. The dust sampler uses an infrared diode as a light source. The intensity of radiation scattered by dust particles is measured with a photodetector which works in the same radiation frequency range. PŁ-2 has been accepted to work in the areas with explosion hazards (I M Ex ia I) and co-operates with the the methane and fire monitoring system SMP-NT, SMP-NT/A (Fig. 9).

The registration and archiving of the measurement data from PŁ-2 optical dust samplers is carried out in a continuous manner in the mine measuring system, similarly to other measuring sensors that are elements of this system. Each PŁ-2 dust sampler is calibrated by coal dust sampled from the mine working in which the counter is going to be installed. The dust samples are put through a sieve with the mesh size of 100 μm. Then a PŁ-2 dust sampler and CIP10R isokinetic dust sampler are placed in a specially constructed chamber which enables to keep continuous dustiness in a long period of time. The calibration is done by comparing the average value of dustiness registered by PŁ-2 in eight hours with the dustiness value registered by the CIP10-R isokinetic dust sampler in the same period of time. During the tests there were three PŁ-2/50 dust samplers used, all made by EMAG.

The testing methodology is based on the following:

- installing previously calibrated three PŁ-2 dust samplers in the top mine working in such a way that the first dust sampler should be placed as close as possible to the face outlet, the second one approximately in the middle of the tested area, while the third one at the end of this area,

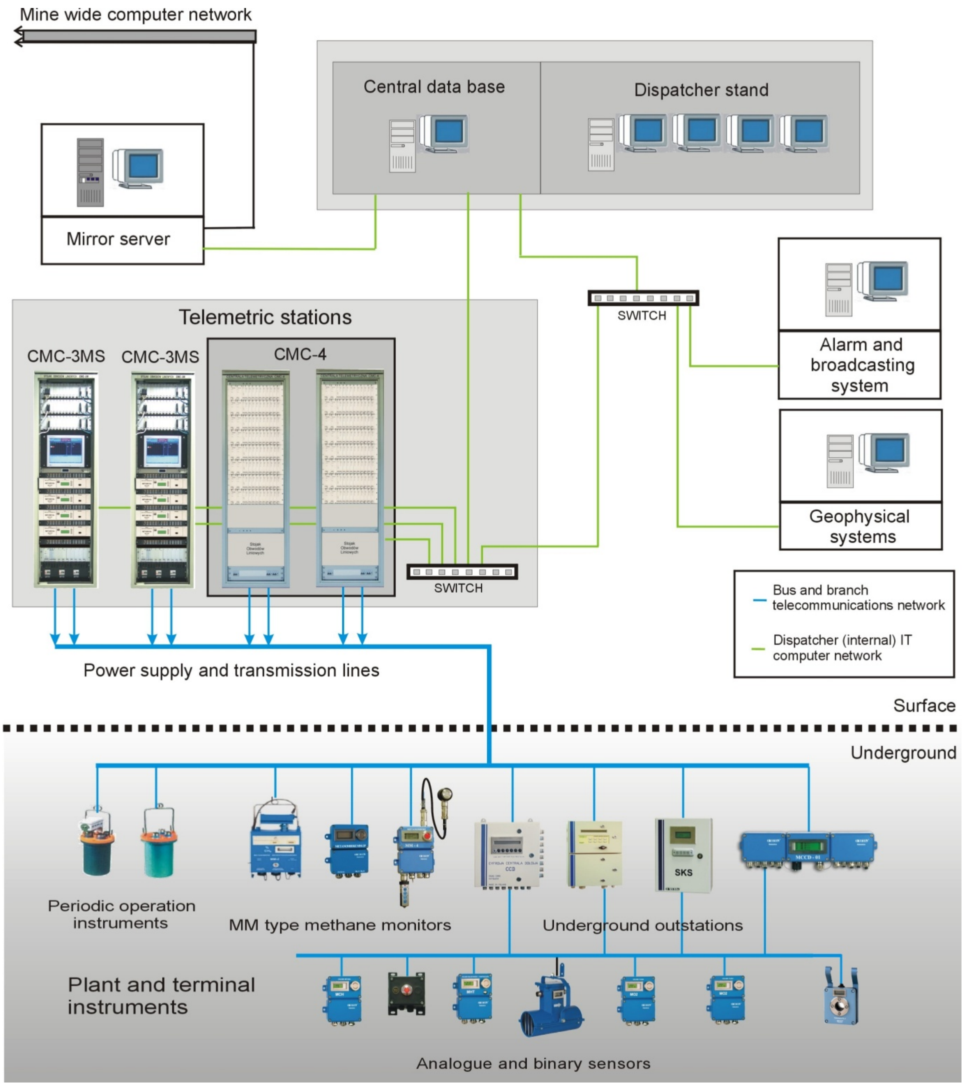

Fig. 9. The structure diagram of the SMP-NT system for automatic monitoring of methane concentration and ventilation in the selected areas of a mine (ITI EMAG)

- registering instantaneous values of dust concentration in the period of at least 24 hours,
- taking samples of deposited dust from the places where sensors are installed and performing a granular analysis on them,
- determining the average distribution of dust concentration for the given mine working based on the registered measurement results,
- determining the quality coefficient of dust depositing *b*,
- determining the quantity coefficient of dust depositing *k*,

- determining a coefficient with the use of a laboratory method, by measuring the coal dust concentration with an isokinetic dust sampler with a head for the total fraction, and referring the results to the average values of concentration registered by optical dust samplers,
- determining the spatial distribution of dust concentration loss,
- further registration of dust concentration in the mine working by means of a dust sampler located as close as possible to the dustiness source (face outlet),
- calculating the intensity of dust depositing on the basis of registered measurement results of dust concentration and the determined dustiness distributions.

7. Test results

The tests performed in a mine showed that the use of the exponential model of the average distribution of dust in the mine working, in connection with continuous measurement of dust concentration, enables to determine the intensity of coal dust depositing in a given section of the mine working. As a result of the conducted tests, the values of coal dust depositing intensity were achieved, expressed in grams per square meter per 24 hours. Their maximal and minimal values are presented in Table 1.

TABLE 1

Maximal and minimal values of dust depositing intensity resulting from the tests

	Face U		Face Z		Face Y	
	max.	**min.**	**max.**	**min.**	**max.**	**min.**
Dust depositing intensity M_o [g/m^2/24h]	2628.9	1174.0	3903.6	2237.4	4357.1	1570.6

The performed calculations showed that in a 300-m section of the top mine working there could be the volume of dust amounting to about 0.2 percent of the 24-hour average mining output in the face. The remaining part of the produced dust is transported further away by the ventilation air, yet the majority remains in the face and than in goafs. The tests demonstrated a linear dependency of the dust depositing intensity on the intensity of the dust source. The characteristics illustrating this dependency for each of the tested mine workings can be seen in Fig. 10.

The values of coal dust depositing intensity determined during the calculations are significantly higher than the values quoted in literature and the data provided by coal mines. The first reason for this is the fact that the tested method does not take into account the content of solid non-combustible parts. The second reason is that the method does not take into account the dust which is deposited not only on the floor but also on all technical elements of the mine working equipment and on the walls.

Additionally, the conducted tests proved the variability of the qualitative and quantitative dust depositing coefficients depending on the intensity of the dust source. Minimal and maximal values of the *b* and *k* coefficients resulting from the tests are presented in Table 2.

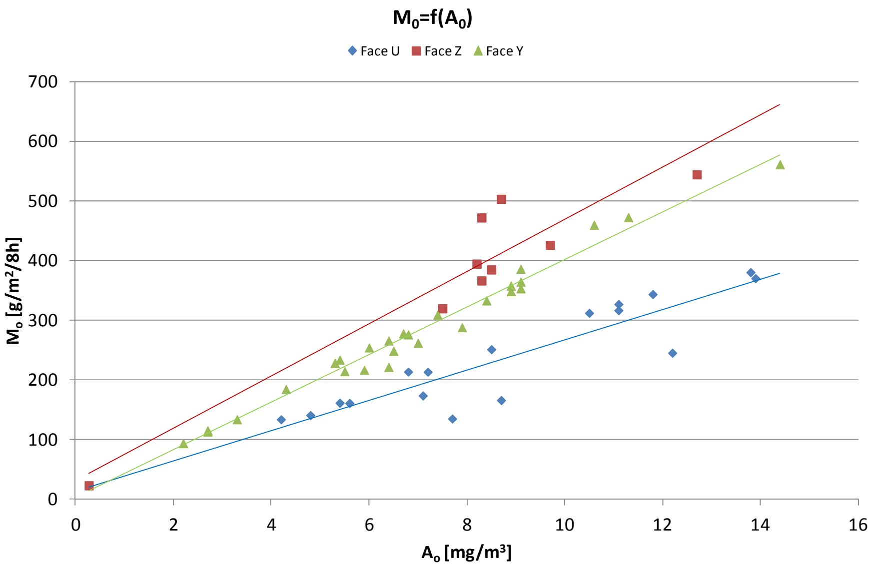

Fig. 10. Dependency of the coal dust depositing intensity (M_o) on the average dust source intensity (A_0)

TABLE 2

Minimal and maximal values of the ***b*** and ***k*** coefficients resulting from the tests

Coefficient	Face U		Face Z		Face Y		Total	
	max.	**min.**	**max.**	**min.**	**max.**	**min.**	**max.**	**min.**
b * 1E-06 [1/m]	4658	1686	4847	2721	4950	2569	4950	1686
k * 1E-06	4648	1681	4835	2717	4938	2566	4938	1681

However, the variability of these coefficients does not have significant impact on the proposed risk assessment method of dust explosion. Due to the fact of its being a relative method, the calculations should be done with the lowest-value coefficients, as such low values reflect the worst condition, i.e. the fastest dust depositing.

8. Conclusions

The use of the optical method of continuous monitoring of airborne respirable dust in the air and the mathematical model of the average distribution of dust concentration determined for the given mine working, in combination with proper software, can be used to assess the deposited dust explosion risk. The assessment of the deposited dust explosion hazard can be conducted based on the observation of coal dust depositing intensity in the mine working, calculated on the basis of the determined distributions and continuous measurement of dust concentration, expressed in mass unit per area per time. The presented model and the spatial distributions of dust calculated on the basis of this model demonstrate very well the character of the phonomenon of transport

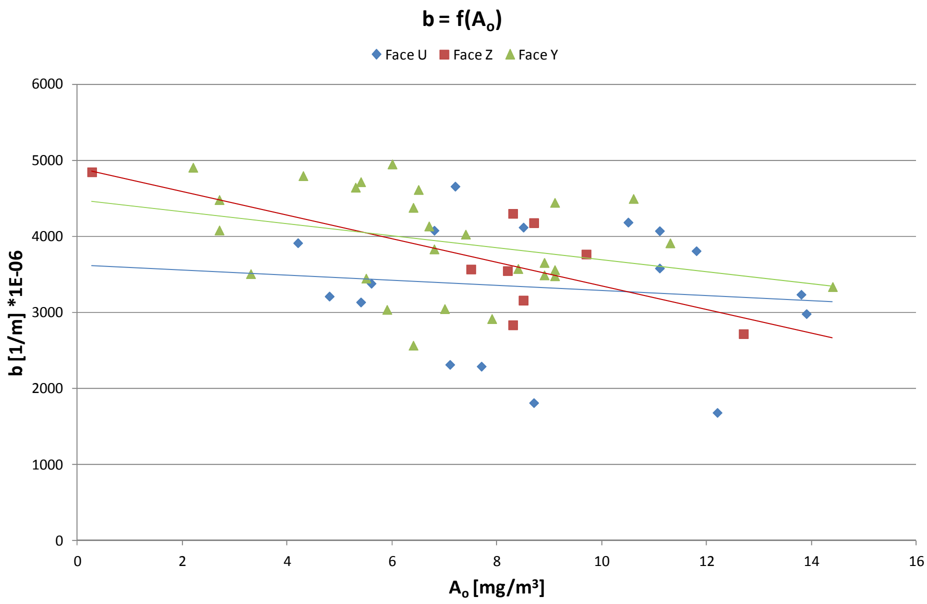

Fig. 11. Dependency of the value of the quality dust depositing coefficient (b) on the average dust source intensity (A_o)

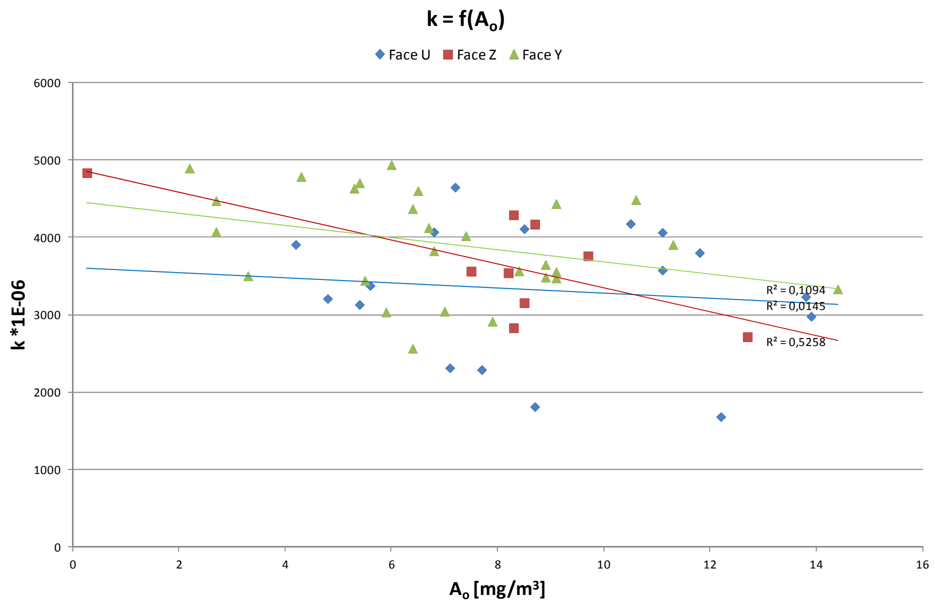

Fig. 12. Dependency of the value of the quantity dust depositing coefficient (k) on the average dust source intensity (A_o)

and depositing of dust particles in the mine working. As the concentration of dust deposited in the air is a non-metrology quantity which does not have an unequivocal pattern, the presented optical method for the assessment of the coal dust explosion risk based on continuous optical measurements of dust concentration is a relative method.

The values of the coal dust depositing intensity depend on the assumed *b* and *k* coefficients and, additionally, are burdened with a measurement method error. The values of the quality and quantity dust depositing coefficients (*b* and *k*) depend on the ventilation conditions in the mine working (air flow velocity), dust source intensity and the assumed length of the mine working zone for which the calculations are performed. While performing the calculations it is necessary to use the lowest-value coefficients referring to the fastest dust depositing. The PŁ-2 stationary optical dust sampler is now the only device compliant with the requirements stipulated for anti-explosion equipment which allows constant monitoring of dust concentration and which can be used in the underground of mines, in the areas with the “a”, “b” and “c” categories of explosion hazards, as well as in the zones categorized as Z1 and Z2 methane explosion hazard zones.

The application of the optical method of continuous monitoring of dust depositing in the mine working into the mining practice as an element of the explosion risk assessment can significantly improve the security in this domain and can become a good tool to monitor and assess anti-explosion prevention actions. The presented method of the dust explosion risk assessment is a prospective method. It is necessary to continue the research to improve its unequivocality and to improve the measuring equipment for continuous measurement of dust concentration.

The presented method was submitted to the Polish Patent Office as an invention called: “The method to determine the intensity of coal dust depositing in the mine working on the basis of continous optical measurements”.

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