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Experimental study of coal dust deposition in mine workings with the use of empirical models

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ABSTRACT

Empirical models, developed on the basis of the results of tests on dust deposition and changes in concentration of dust in the protective zone, are the proposed tools to reduce risk of coal dust explosion. The paper presents possible applications of such models to assess and monitor volume of dust in a protective zone. Underground tests were conducted in the tailgate and headgate of longwall 121 of Brzeszcze Coal Mine. Basing on the analysis, the empirical models describing relationship between changes in dust concentration, and dust deposition in a protective zone of roadways: headgate and tailgate of longwall 121 in Brzeszcze Coal Mine, were developed. The developed models show a possibility of predicting explosive dust deposition in a protective zone. After additional research is run, it is planned to generalise the developed empirical model, which will enable monitoring of protective zones.

1. Introduction

Construction of protective zone (at least 200 m of mine working) to prevent propagation of explosions is an obligation imposed on coal mines, which excavate coal in mine workings of class A or class B of coal dust explosion hazard (Cybulski, 2004, Du, Huang, Kuai, Yuan, & Li, 2012). Mine workings located in protective zones must be washed with water or stone dusted (Amyotte, 2006) at a length of at least 200 m from a possible source of explosion (Cybulski, 2004). The above-mentioned actions are effective provided that the protective zone is duly maintained (Cybulski & Malich, 2014). Means that within entire mine working stone dust is minimum 80% out of all dust or water content prevents coal dust from floating and disables volatility (Kuai et al., 2011). Frequency of the maintenance work is crucial and it depends on dust deposition in a mine working (Eckhoff, 2003, 2005) Quality and efficiency of protective zones largely depend on the quality of preventive measures undertaken (Cybulski, 2004, Frank, 2004). Changeable mining conditions can influence coal dust deposition, which may result in failure in using protective zones.

Within the framework of MEZAP research project financed by the National Centre for Research and Development was realized by the following consortium: KOMAG Institute of Mining Technology, Central Mining Institute and Kompania Węglowa S.A. Research work was conducted aiming at determination of dust deposition through the measurements of its concentration in a protective zone. Preliminary results of the tests were used in developing the first empirical model of these dependencies (Prostański et al., 2014).

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2. Research methodology

Measurements of dust deposition and dust concentration were taken in protective zone adjacent to longwall no. 121 in Brzeszcze Coal Mine. Measurements of dust deposition were taken by GIG-KD Barbara's specialist (Malich et al., 2013), measurements of the volume and distribution of dust and changes in its concentration were taken by KOMAG's specialists (Prostański et al., 2014).

Additionally the following conditions in the testing area were determined: air temperature, humidity and flow speed. Conditions during tests are presented in Table 1.

Fig. 1 presents a sketch of longwall no. 121 with adjacent mine workings: tailgate (ventilation) and headgate (haulage). Air was delivered to the longwall along the headgate. Then it flowed along the longwall and the tailgate. Average and short-term concentration of dust in the mine workings was measured with optical dust meters PŁ-2.[1] Measurements of deposited dust and dust lying along the whole protective zone were also taken. In both mine workings, the zones were at least 200 m long, starting from the longwall face.

Samples of dust were collected on measuring plates attached to the sidewalls on the left and on the right as well as on the floor of a mine working. Measurements were taken in nine measuring points in a cross-section of a mine working (Fig. 2), in 10 places along the 200-m-long protective zones of the mine workings located in headgate and tailgate.

Measuring points in both mine workings were located 10 m from the longwall. Samples of dust were being collected on measuring plates for a day. The collected samples were processed and analysed. These were divided into 10 measurement size fractions: from 1000 to 20 μm. Measurements were carried out concurrently at all measurement points in both mine workings. Distances between measurement points were 20 m. Mass of total suspended particulate matter (stone dust and coal dust) [g], mass of coal dust [g] and percentage share of non-combustible particles were determined. Total suspended particulate matter deposition and coal dust deposition, expressed in g/m^2/day and g/m^3/day, were determined.

3. Results and discussion

3.1. Test results

Analysis of results of the tests conducted in headgate of longwall no. 121 in Brzeszcze Coal Mine revealed that dust did not deposit evenly in the mine working, especially at the longwall outlet (Fig. 3). Mass of deposited dust reached approximately 9 g/m^3/day at the front of the protective zone.

It was a consequence of dust carried with the stream of air flowing from the longwall at various speeds. Further from the longwall dust was deposited more evenly within the cross section of the mine working (dust deposition was the highest in the central part of the floor in the working).

[1] Optical dust meter is recording on-line dust concentration of dust particulars smaller than 10 μm.

Table 1 – Conditions of tests conducted in haulage mine working no. 551 of longwall no. 121 (Prostański et al., 2014).

No. of measurement point	1	2	3	4	5	6
Distance from the longwall face [m]	10	30	50	65	80	100
Temperature [°C]	25.3	26.0	27.0	28.0	27	27
Humidity [%]	78.9	78.7	76.2	76.8	76.8	76.5
Air flow speed Vp [m/s]	2.5	2.5	2.5	2.4	2.5	2.0

In the tailgate of longwall no. 121 (Fig. 4a) dust deposition in the mine working was caused by intense works related to installation of pipelines and cabling in the section up to 50 m from the longwall. In further part of the mine workings, dust deposition had an undisturbed decreasing tendency outby the longwall. Conveyors transporting coal from the longwall, and the floor (dust raised by the personnel working there) were the main sources of dust.

Dust deposition in the cross-section of the tailgate (Fig. 4b), was more regular than in the headgate.

The empirical model was developed in order to forecast dust deposition in the protective zone.

To assess combustible coal dust deposition, measurements of deposited dust in a mine working were compared with the measurements of air dustiness taken with the optical method (Fig. 5a).

The measured values were marked respectively:

PK – total suspended particulate matter deposited (stone dust with coal dust),
PW – coal dust,
Pł – total suspended particulate matter (stone dust with coal dust) measured with the optical dust meter.

In headgate no. 552 of longwall 121, measurements of dust concentration taken with PŁ-2 dust meter, were conducted in the protective zone along the section between 40 and 170 m. Results of the measurements showed a relationship between dust deposition and results of measurements of dust concentration with optical dust meters.

Results of measurements of dust deposited and air dustiness in tailgate no. 551, longwall no. 121 (Fig. 5b), showed no correlation between dust deposition and dustiness of dust measured with an optical dust meter. Measurements with optical dust meters showed increasing dust concentration in relation to the measured dust deposition within a distance from the front of tested protective zone.

3.2. Model of dust deposition process in mine workings

Test results were described with exponential function. The function enabled showing all the results of tests of air dustiness in the same way, what facilitated comparing the relationships in the mine workings under tests. The volume of total suspended particulate matter deposition and dust concentration measured with an optical dust meter were compared.

Coefficient of determination R^2 of the function is associated with coefficient of indeterminacy φ^2 through the relation:

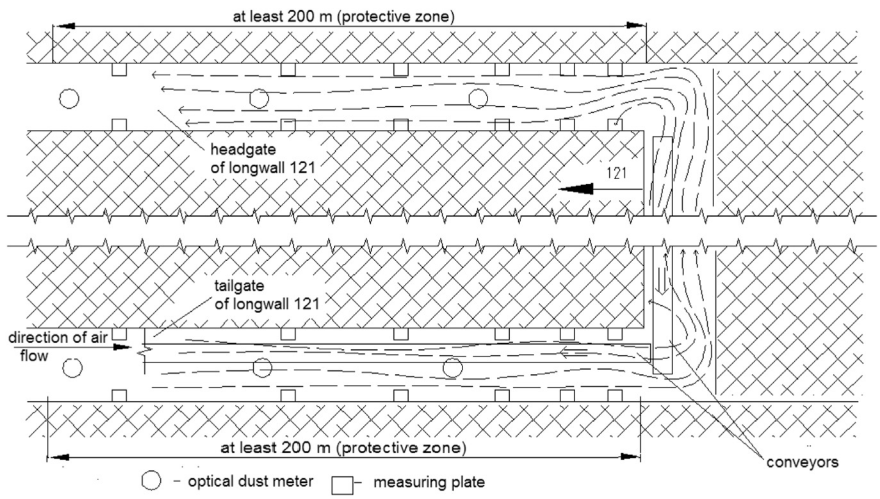

Fig. 1 – Location of measurement points in mine workings in the area of longwall no. 121 (Prostański et al., 2014).

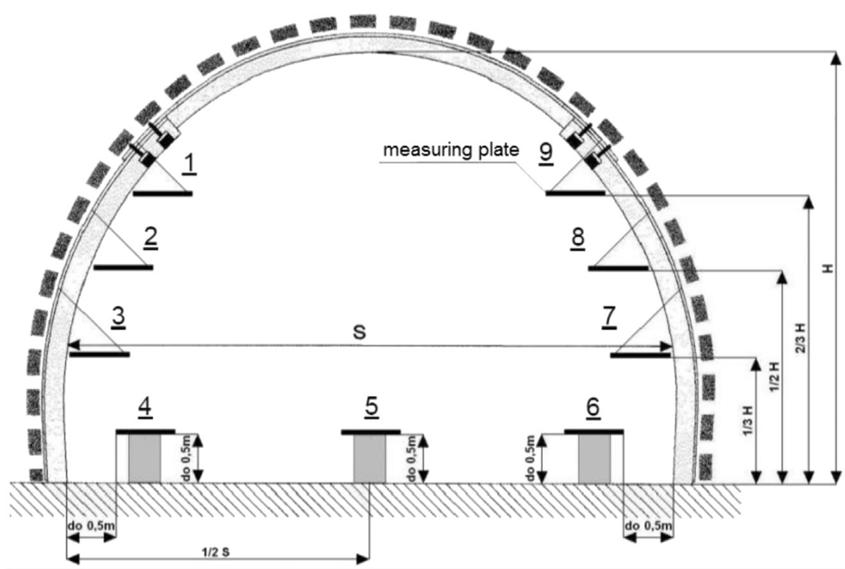

Fig. 2 – Places of collecting samples in a cross-section of a mine working (facing inby) in the protective zone (Malich et al., 2013).

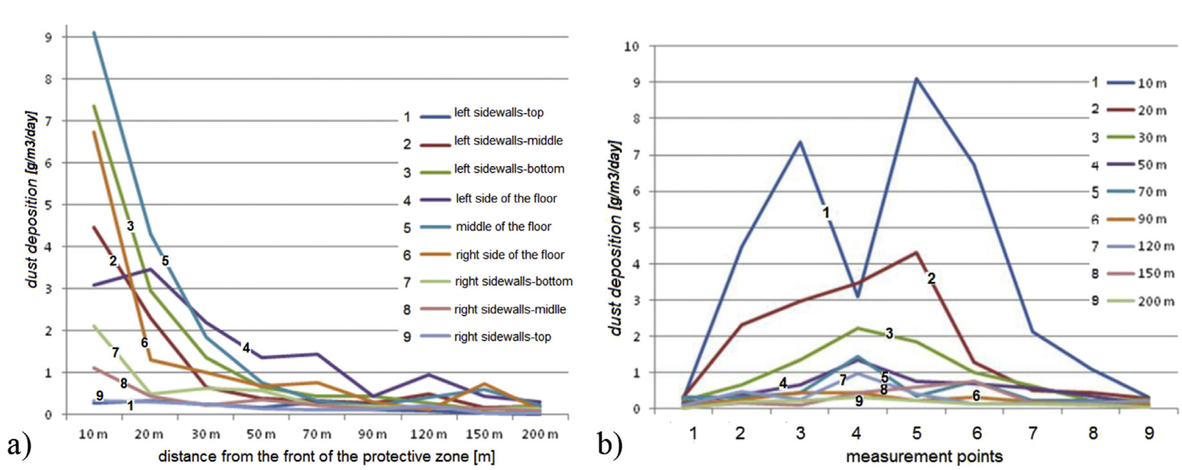

Fig. 3 – Dust deposition along the protective zone – headgate of longwall no. 121, Brzeszcze Coal Mine: a) measurement points in a long of mine working, b) measurement points in a cross-section of a mine working (Prostański et al., 2014).

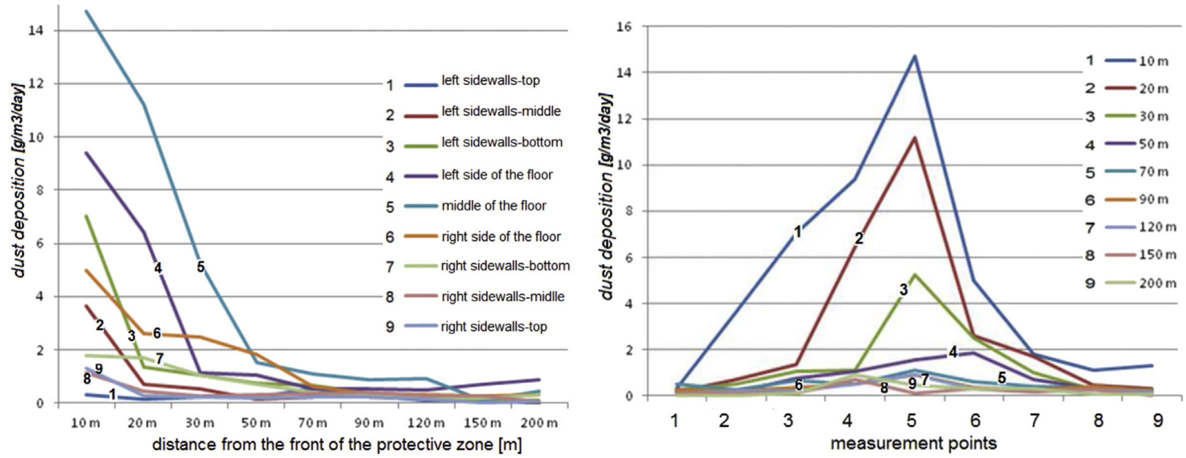

Fig. 4 – Dust deposition along the protective zone – tailgate of longwall no. 121 Brzeszcze Coal Mine: a) measurement points in a long of mine working, b) measurement points in a cross-section of a mine working (Prostański et al., 2014).

$$R^2 = 1 - \varphi^2 \quad (1)$$

Dust deposition in the protective zone, in tailgate no. 551 of longwall no. 121 (Fig. 6a), was described by the exponential function:

$$\ln(Y) = -1.18 \times \ln(X) + 6.14 \quad (2)$$

Coefficient of determination was $R^2 = 0.90$.

Dust concentration measured with an optical dust meter is expressed by the following exponential function:

$$\ln(Y) = 0.09 \times \ln(X) + 1.25 \quad (3)$$

Coefficient of determination was $R^2 = 0.97$.

In headgate no. 552, longwall no. 121 (Fig. 6b), dust deposition in the protective zone was described by the following exponential function:

$$\ln(Y) = -0.97 \times \ln(X) + 5.28 \quad (4)$$

Coefficient of determination was $R^2 = 0.977249$.

Dust concentration, measured with an optical dust meter, is expressed by the following exponential function:

$$\ln(Y) = -0.22 \times \ln(X) + 2.96 \quad (5)$$

Coefficient of determination was $R^2 = 0.99$.

Describing changes in dust deposition and dust concentration in a protective zone enables proper description of measurements results. This was achieved with one type of a function of high coefficient of determination.

The obtained functions were presented as substitute exponential equations, which were applied to extrapolate results of measurements beyond the measurement range. That is how it was possible to obtain correlations between dust concentration and dust deposition in the protective zone.

It was suggested to describe the processes of dust deposition and dust concentration along tailgate no. 551, longwall no. 121 (Fig. 7a) with the following equations:

Dust concentration:

$$y = x^{0.09} \times 3.49 \quad (6)$$

and dust deposition:

$$y = x^{-1.18} \times 464.15 \quad (7)$$

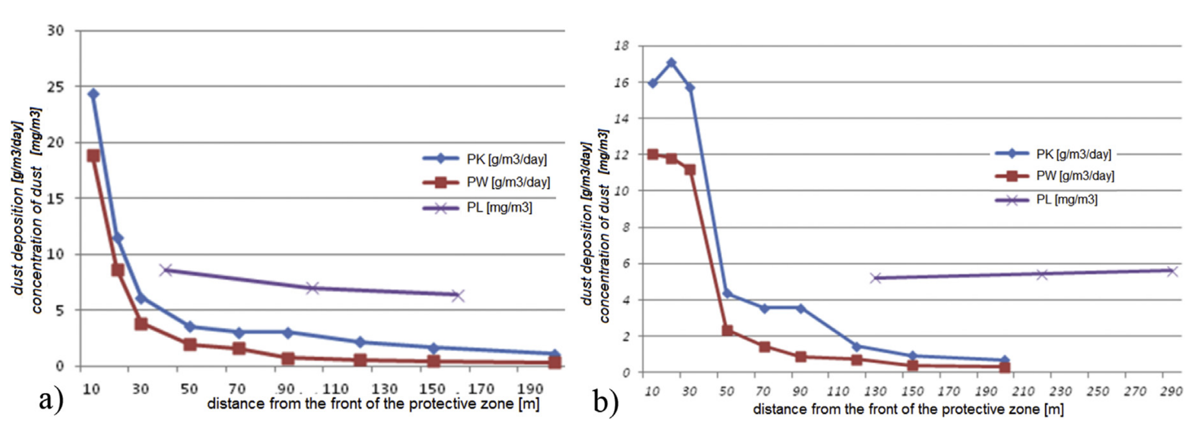

Fig. 5 – Comparison of results of coal concentration made with optical dust meter and results of measurements of dust deposition obtained with measurements plates in the protective zone: a) headgate no. 552, longwall no. 121, tailgate no. 551, longwall no. 121 (Prostański et al., 2014).

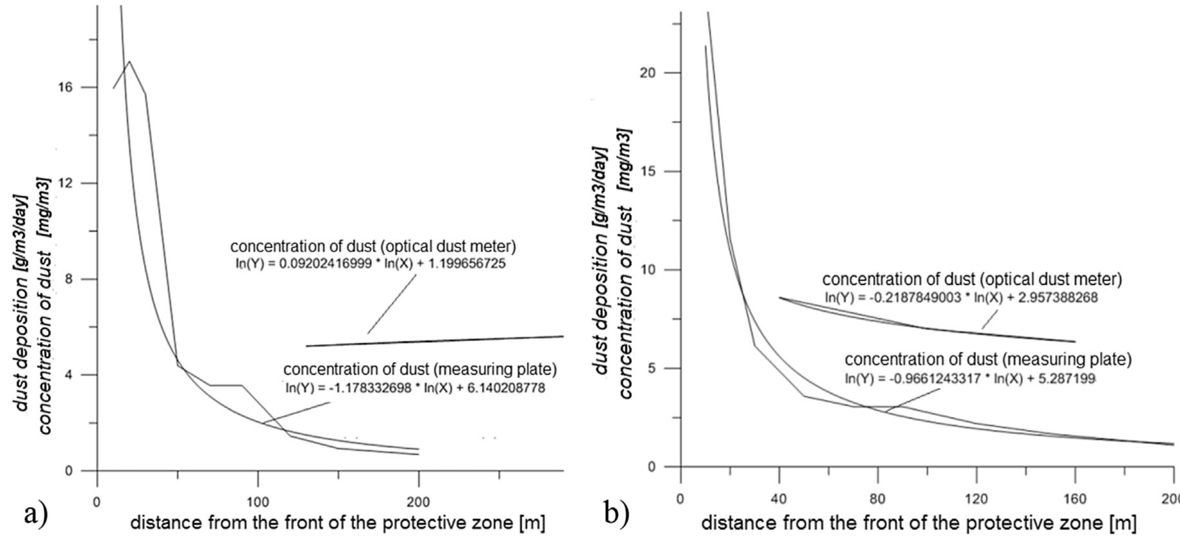

Fig. 6 – Diagram of dust concentration and dust deposition in the protective zone: a) tailgate no. 551, longwall no. 121, b) headgate no. 552, longwall no. 121 (Prostański et al., 2014).

Functions extrapolating results of measurements in headgate no. 552 of longwall no. 121 (Fig. 7b), for dust deposition is expressed by the following equation:

$$y = x^{-0.97} \times 197.79 \quad (8)$$

For dust concentration, the extrapolated results are described by the following equation:

$$y = x^{-0.22} \times 19.25 \quad (9)$$

To predict distribution of dust concentration and dust deposition in protective zone, functional dependence of the obtained characteristics was visualised in a form of one exponential function. The dependencies may be applied to automate selection of criteria for the designed protective zones.

With the use of the devised equations, for each of the extrapolated cases, an empirical model was build, describing relationships between functions of dust deposition and dust concentration.

For the ventilation headgate no. 552 of longwall no. 121 (Fig. 8a), the dependence was described by an empirical model in a form of the exponential function:

$$\ln(Y) = 4.42 \times \ln(X) - 7.78 \quad (10)$$

presented in form of the following equation:

$$Y = X^{4.42} \times 0.0004 \quad (11)$$

Empirical model developed for tailgate no. 551 of longwall no. 121 (Fig. 8b), also takes the form of an exponential function. For haulage tailgate no. 551, the model was described with the following function:

$$\ln(Y) = -0.08 \times \ln(X) + 1.68 \quad (12)$$

presented in form of the following equation:

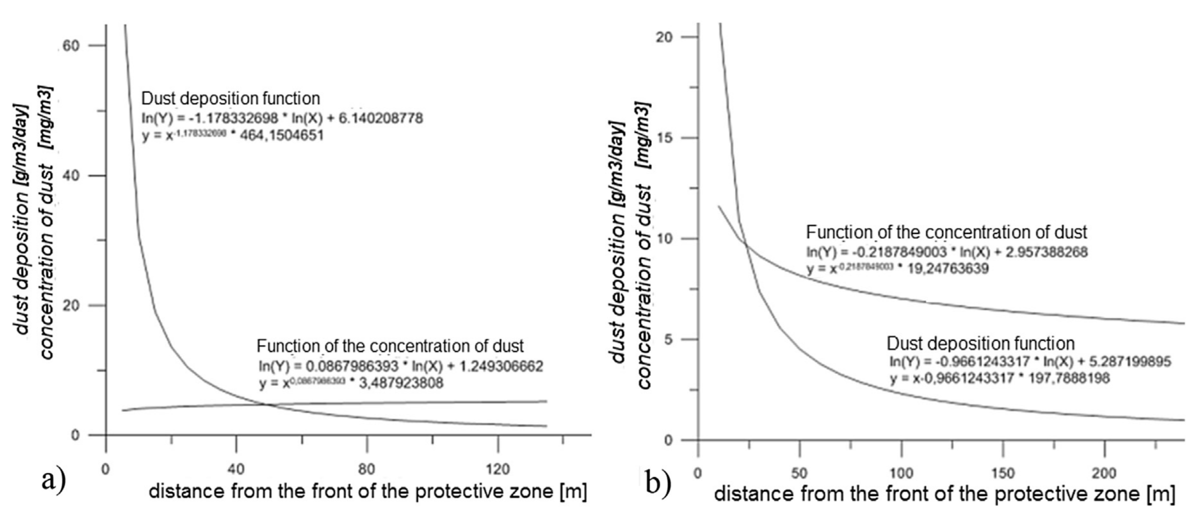

Fig. 7 – Diagram of dust concentration and dust deposition in the protective zone of: a) tailgate no. 551 of longwall no. 121, b) headgate no. 552 of longwall no. 121 (Prostański et al., 2014).

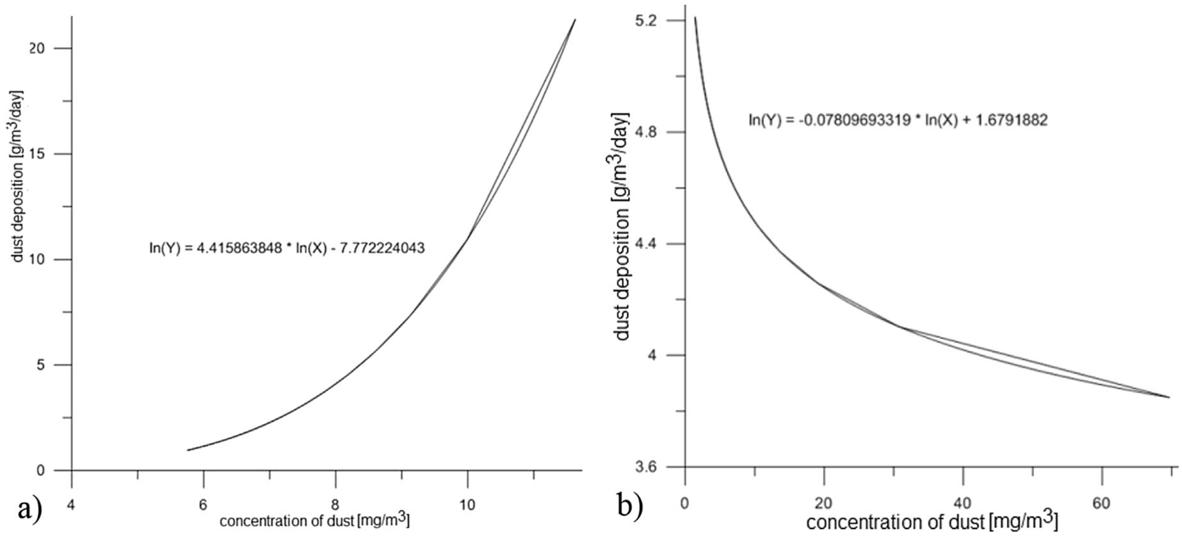

Fig. 8 – Empirical model of dust deposition dependant on dust concentration in air: a) headgate no. 552 of longwall no. 121, b) tailgate no. 551 of longwall no. 121 (Prostański et al., 2014).

$$Y = X^{-0.08} \times 5.37 \quad (13)$$

The models consider only relationships between the results of measurements of dust concentration and dust deposition. After further tests are run, the models will be updated with information concerning air flow velocity in a mine working, cross-sectional area of mine workings, air temperature and humidity.

4. Conclusions

Creating a protective zone requires knowledge of dust deposition along its length. Dust should be neutralized if exceeds certain level to satisfy proper standard of work safety.

Assessment of explosive coal dust deposition is related to the measurements of dust concentration resulting from the mining process and other conditions i.e.: ventilation, humidity and temperature and coal properties.

To do so, tests of dust deposition and dust concentration were conducted in the mine workings: headgate no. 552 and tailgate no. 551, adjacent to longwall 121.

Measurements of dust deposition and dust concentration can be described by a function.

Data analysis and dust deposition depending on dust concentration enabled assuming an exponential function to describe it.

Assumed function has high coefficient of determination. This proves that models are well adjusted to results of research.

It enabled representing all dependencies in the same way and its comparison with reference to specific mine workings.

Empirical model of dust deposition depending on dust concentration, measured in the protective zone, was described by the exponential function of high coefficient of determination which enabled, with high probability, proper description with the measurement results.

Afterwards the functions were transformed into exponential equations and the results of measurements were extrapolated beyond the measurement range. Thus, it was possible to visualise the dependence between dust concentration and dust deposition along the entire protective zone.

Extrapolated measurement results, described mathematically and presented in graphs, visualise probable dust distribution and collection in the protective zone. The obtained dependences may be used in determining the criteria to establish protective zones.

Presented models are first developed basing on results of research. In framework of MEZAP it is predicted to develop five subsequent models. These models will allow elaborating generalized model, which may be tested in coal mines.

Generalized empirical model will be used to prepare monitoring system and to predict intensity of dust deposition in mine workings.

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