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IMPACT OF COAL OUTPUT CONCENTRATION ON METHANE EMISSION TO LONGWALL FACES

WPŁYW KONCENTRACJI WYDOBYCIA NA WYDZIELANIE METANU DO WYROBISK ŚCIANOWYCH

An increase in concentration of coal output in Polish hard coal mines contributes to a significant increase in absolute methane-bearing capacity in mining areas. Measurements of methane concentration were taken in selected longwall faces in order to estimate the influence of coal output on methane hazard. The measurements were taken from 2006 to 2008 in 8 longwalls in mines with high methane hazard. The parameters for longwalls where measurements were taken are presented in table 1. Average daily output ranged from 1380 to 2320 Mg: however the maximum daily output amounted to 5335 Mg. Absolute methane-bearing capacity ranged from 4.44 to 56.41 m^3/min. Longwalls were ventilated with a U and Y system and their ventilation schemes are presented in figure 1. The period of measurements ranged from 29 to 384 days. The results obtained were used to determine the influence of changes in output on methane hazard.

For each longwall under research statistical estimation of parameters, such as: ventilation air methane (VAM) emission, amount of methane captured by a drainage system, absolute methane-bearing capacity and an advance of longwall face was conducted. In order to determine the influence of a longwall face advance on methane-bearing capacity the probabilistic model of the distribution of those parameters on the basis of the measurement results was used.

In order to determine the dependence between ventilation air methane emission, methane drainage, absolute methane-bearing capacity and longwall advance, the distribution of analysed variables was checked by means of Kolmogorow-Smirnov normality test. The results of this test are presented in table 2. Table 3 presents values for correlation co-efficient $r(x,y)$. When analyzing the results presented in table 3 it must be observed that in case of most longwalls there is a high correlation between ventilation air methane emission, absolute methane-bearing capacity and longwall advance. However, in longwalls N-10 i W-5 the correlation between methane drainage capture and longwall advance is equally strong. In all other longwalls the correlation is average. In all cases the correlations were positive, which means that together with an increase in advance, there is also an increase in ventilation air methane emission, methane drainage capture and absolute methane-bearing capacity

On the basis of determination co-efficient it can be concluded that in cases under consideration at least half (about 50%) of results, ventilation air methane emission, methane drainage capture and absolute methane-bearing capacity can be explained linearly by an influence of longwall advance, while this statement can be assumed with the probability close to 100%.

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It should also be added that the lack of very high or full correlations means that examined parameters do not fully show linear dependence; however there might be other functional correlations. Because of a complex character of phenomena happening during mining it is not possible to determine full correlations. However, the interpretation of results allows us to claim that an influence of wall advance on methane emission amounts to 30 to 70% depending on a given case. Therefore, other factors, for example geological ones, which were not taken into consideration, will contribute to the level of methane hazard.

Table 4 presents determined co-efficients of linear regression. On the basis of the data in table 4, an equation describing the dependence of absolute methane-bearing capacity in a longwall on a longwall advance in the form (11) can be formed. Table 5 presents determined co-efficients of non-linear regression. On the basis of the data in table 5, an equation describing the dependence of absolute methane-bearing capacity in a longwall on a longwall advance in the form (13) can be formed.

When comparing co-efficient R^2 of the contribution of the explained variance in tables 4 and 5 it can be obcserved that non-linear dependence explains better the results of mining measurements. The similar dependence presenting methane emission as dependent on output is suggested by Myszor (1985). The conditions for safe mining can be given for a determined methane emission.

Keywords: mehane hazard, methane-bearing capacity, coal output, face advance

Wzrost koncentracji wydobycia w polskich kopalniach węgla kamiennego przyczynia się do znaczącego wzrostu metanowości bezwzględnej rejonów eksploatacyjnych. W celu oceny wpływu wydobycia na stan zagrożenia metanowego przeprowadzono pomiary stężenia metanu w wybranych wyrobiskach ścianowych. Pomiary przeprowadzono w latach 2006÷2008 w 8 wyrobiskach ścianowych w kopalniach charakteryzujących się dużym zagrożeniem metanowym. Parametry charakteryzujące wyrobiska ścianowe, w których prowadzono pomiary zestawiono w tablicy 1. Wydobycie średnie w ciągu doby zmieniało się od 1380 do 2320 Mg, natomiast maksymalne wydobycie w ciągu doby dochodziło do 5335 Mg. Metanowość całkowita zawierała się w przedziale od 4,44 do 56,41 m^3/min. Ściany były przewietrzane w systemie na U i Y a ich schematy przewietrzania przedstawiono na rysunku 1. Okres badań w poszczególnych ścianach również był różny i zawierał się od 29 do 384 dni. Uzyskane wyniki posłużyły do określenia wpływu zmian wydobycia na stan zagrożenia metanowego.

Dla każdej badanej ściany przeprowadzono ocenę statystyczną parametrów takich jak: metanowość wentylacyjna, ilość metanu ujmowanego odmetanowaniem, metanowość całkowita i postęp ściany. Dla określenia wpływu postępu ściany na metanowość wykorzystano model probabilistyczny rozkładu tych parametrów na podstawie wyników obliczeń.

W celu określenia zależności pomiędzy wartością metanowości wentylacyjnej, odmetanowaniem i metanowości całkowitej a postępem ściany sprawdzono kształt rozkładu analizowanych zmiennych w oparciu o test normalności Kołmogorowa-Smirnowa. Wyniki testu normalności metanowości całkowitej, metanowości wentylacyjnej i postępu w trakcie prowadzenia ścian, przedstawiono w tablicy 2. W tablicy 3 zamieszczono wyznaczone wartości współczynnika korelacji $r(x,y)$. Analizując zamieszczone w tablicy 3 wyniki należy zauważyć, że w większości ścian występuje wysoka korelacja pomiędzy metanowością wentylacyjną i całkowitą a postępem ściany. Natomiast pomiędzy odmetanowaniem a postępem ściany związek ten jest równie silny w ścianach N-10 i W-5. W pozostałych ścianach korelacja jest przeciętna. We wszystkich przypadkach korelacje były dodatnie, co oznacza, że wraz ze wzrostem postępu następuje wzrost metanowości wentylacyjnej, odmetanowania i metanowości całkowitej.

Na podstawie współczynnika determinacji można powiedzieć, że w rozważanych przypadkach, co najmniej w połowie wyników (około 50%), metanowość wentylacyjna, odmetanowanie i metanowość całkowita może zostać wytłumaczona liniowo wpływem postępu ściany, przy czym można to stwierdzenie przyjąć z prawdopodobieństwem bliskim 100%.

Należy dodać, że brak bardzo wysokich, czy pełnych korelacji oznacza, że badane parametry nie w pełni wykazują zależność liniową, niemniej jednak mogą istnieć inne powiązania funkcyjne. Ze względu na złożony charakter zjawisk zachodzących w trakcie prowadzonej eksploatacji nie można jednoznacznie wykazać pełnych powiązań. Jednak interpretacja wyników pozwala na stwierdzenie, że wpływ postępu ściany na wydzielanie metanu wynosi od 30 do 70% w zależności od rozważanego przypadku. Zatem inne czynniki np. geologiczne, których nie uwzględniono w rozważaniach będą miały pozostały udział w poziomie zagrożenia metanowego.

W tablicy 4 przedstawiono wyznaczone współczynniki regresji liniowej. W oparciu o dane z tablicy 4 można napisać równanie opisujące zależność metanowości całkowitej w wyrobisku ścianowym od postępu ściany w postaci (11). W tablicy 5 przedstawiono wyznaczone współczynniki regresji nieliniowej. W oparciu o dane z tablicy 5podano równanie opisujące zależność metanowości całkowitej w wyrobisku ścianowym od postępu ściany w postaci (13).

Porównując współczynnik R^2 udziału wyjaśnionej wariancji w tablicach 4 i 5 można stwierdzić, że zależność nieliniowa lepiej wyjaśnia wyniki uzyskane z pomiarów kopalnianych. Podobną zależność ujmującą wydzielanie metanu od wielkości wydobycia proponuje Myszor (1985). Dla określonego wydzielania metanu można podać warunki bezpiecznego prowadzenia eksploatacji.

Słowa kluczowe: zagrożenie metanowe, metanowość bezwzględna, wydobycie, postęp przodka

1. Introduction

An increase in output concentration in Polish coal mines contributes to a considerable increase in absolute methane-bearing capacity of mining areas (Cybulski & Myszor, 1974; Kubaczka, 2009; Szlązak & Borowski, 2004). Then there is an increased methane emission in longwalls in mines that are considered to have low methane hazard, which are unprepared for effective methane prevention, including methane drainage. Rock mass methane drainage from roadways during longwall mining is a very effective method for reducing methane hazard (Berger &Markowski, 2010; Dziurzyński & Krach, 2009).

During longwall mining, methane is emitted from different sources, whose localisation as well as methane quantity decide about how great a hazard is and what kind of prevention method is selected. The main source of methane emission is coal seams as methane is a gas which is strictly connected with carbonization processes and coal deposits' formation. The level of coal seams' saturation with methane depends on many factors, first of all on the presence or absence of impermeable isolating rock layers in overburden, not allowing or allowing for degasification and free methane outflow from coal seam to surrounding rocks (Sporysz, 2009).

Therefore, in coal mining there is a great variety in the level of coal seams' saturation, starting from non-methane, which contain only its insignificant amount, where there is no isolating overburden and finishing with high methane seams located close to impermeable mudstones and shales.

It would be impossible to conduct mining if special prevention methods (ventilation, methane drainage) were not used in seams with high methane hazard. Controlling methane hazard also depends on other natural hazards (eg burst, fire) in case of which prevention methods are often incompatible with methane prevention methods (Szlązak & Szlązak, 2001; Szlązak & Zasadni, 2004). Therefore, safety in mines with seams saturated with methane depends on proper estimation of methane hazard, designed forecasts, observation and control over hazard as well as preventative steps.

2. Selection and characteristics of examined longwalls

Measurements of methane concentration were taken in selected longwall faces in order to estimate the influence of coal output on methane hazard. The results obtained were used to determine the influence of changes in output on methane hazard (Kubaczka, 2009).

The measurements were taken from 2006 to 2008 in 8 longwalls in mines with a high methane hazard. The parameters for longwalls where measurements were taken are presented in table 1. Average daily output ranged from 1380 to 2320 Mg: however the maximum daily output amounted to 5335 Mg. Absolute methane-bearing capacity ranged from 4.44 to 56.41 m^3/min. Longwalls were ventilated with a U and Y system and their ventilation schemes are presented in figure 1. The period of measurements ranged from 29 to 384 days.

3. Research methodology

In order to estimate methane emission to longwalls depending on output, reserch was conducted in 10 longwalls in 4 mines with high methane hazard (Kubaczka, 2009).

Measurements of methane concentration in particular cross-sections of a roadway:

- head entry – 10 m behind the crossroads,
- tail entry – 10 m before the end, over the drive or 10 m behind tail entry in a tail gate,
- exit from longwall panel – 10 m before tail gate and incline crossing.

Built-in automatic methane sensors were used to measure methane concentration. Independently of those measurements, the measurements of air velocity were taken as well as advance or output from longwall were determined. The scheme for localization of measurement points for methane concentration are presented in Fig. 1. Sensors for determining methane concentration and air velocity were periodically checked and their measurements were compared to the ones conducted in a roadway cross-section. Average concentrations for the whole day were determined on the basis of metanometry results.

The data were gathered in large collections and average values were determined according to the following dependence, based on computer programme "Statistica 8.0":

$$c_{sr} = \frac{\sum_{i=1}^{n} c_i}{n} \tag{1}$$

where:

c_i — methane concentration measured by a metanometric sensor,
n — number of measurements of methane concentration taken during a day.

The results obtained in such a way allowed to determine a gain in the amount of methane emitted to a longwall. Independently of those measurements, the amount of drained methane by means of a methane drainage capture system was controlled.

4. Estimation of changes of parameters characterising methane hazard in longwalls

For each longwall under research, statistical estimation of parameters such as: ventilation air methane emission, amount of methane drained by means of methane drainage, absolute methane-bearing capacity and longwall advance was conducted.

TABLE 1

Parameters of longwalls where measurements were taken

No.	Specification	Longwall							
1	Mine	**X-1**	**X-1**	**X-1**	**X-1**	**X-2**	**X-3**	**X-3**	**X-4**
2	No. of longwall	**C-6**	**F-2**	**F-27**	**G-6a**	**B-7**	**N-10**	**N-15**	**W-5**
3	Seam	**417/1**	**405/1**	**404/2**	**409/4**	**358/1**	**329/1-2**	**328/1**	**360/1**
4	Thickness of seam, m	1,55-2,6	2,0-2,32	1,85-2,2	3,00	1,9-2,1	1,4-1,9	1,45-1,75	1,9-2,1
5	Width of longwall, m	210	190	210	220	205	220	180	200
6	Length of longwall panel, m	460	400	520	220	425	760	1000	900
7	Depth, m	817-908	870-880	725-765	886-938	968-996	676-806	792-874	910-950
8	Roof rocks	clay shale, arenaceous shale	clay shale, arenaceous shale	clay shale,	clay shale, arenaceous shale	clay shale, arenaceous shale	clay shale, arenaceous shale	clay shale	arenaceous shale, send-stone
9	Floor rocks	arenaceous shale, sendstone	clay shale, arenaceous shale	clay shale, arenaceous shale	clay shale, arenaceous shale	arenaceous shale, send-stone	clay shale, arenaceous shale	clay shale, arenaceous shale	clay shale, arenaceous shale
10	Coal output, maximum, Mg/d	3730	3740	3530	3120	5335	4690	4460	2730
11	Coal output, average, Mg/d	1810	1520	2020	1450	2060	1380	1830	2320
12	Vented methane-bearing capacity, average, m^3/min	4,44	14,49	20,38	19,91	40,32	14,77	28,84	9,54
13	Drained methane capacity, average, m^3/min	0,00	6,82	11,57	11,73	16,09	9,64	16,96	1,24
14	Absolute methane-bearing capacity, m^3/min	4,44	21,31	31,95	31,64	56,41	24,41	45,80	10,78
15	Method of roof control	caving	caving	caving	caving	caving	caving	caving	caving
16	Ventilation system	U	U	U	U	Y	U	U	Y
17	Mining in destressed or non-destressed zone	60 m above 415/3-4 seam	50 m above, 404/4 seam	55 m above, 403/1 seam	150 m above, 407/1 seam	non-destressed	non-destressed	non-destressed	non-destressed
18	Neighbourhood of goaf in the same seam	no	no	yes	yes	yes	yes	yes	yes
19	Direktion of working (retreating, advanc-ing)	retreating	retreating	retreating	retreating	retreating	retreating	retreating	retreating
20	Date of starting samples	02-04-2007	31-08-2006	05-04-2006	11-11-2007	20-09-2007	13-03-2007	02-07-2007	01-06-2008
21	Date of ending samples	22-11-2007	31-01-2007	22-08-2006	15-01-2008	25-03-2008	31-03-2008	31-03-2008	30-06-2008
22	Number of days	234	153	139	188	187	384	273	29
23	State of working	working	working	working	working	working and non-woring	working	working and non-woring	working

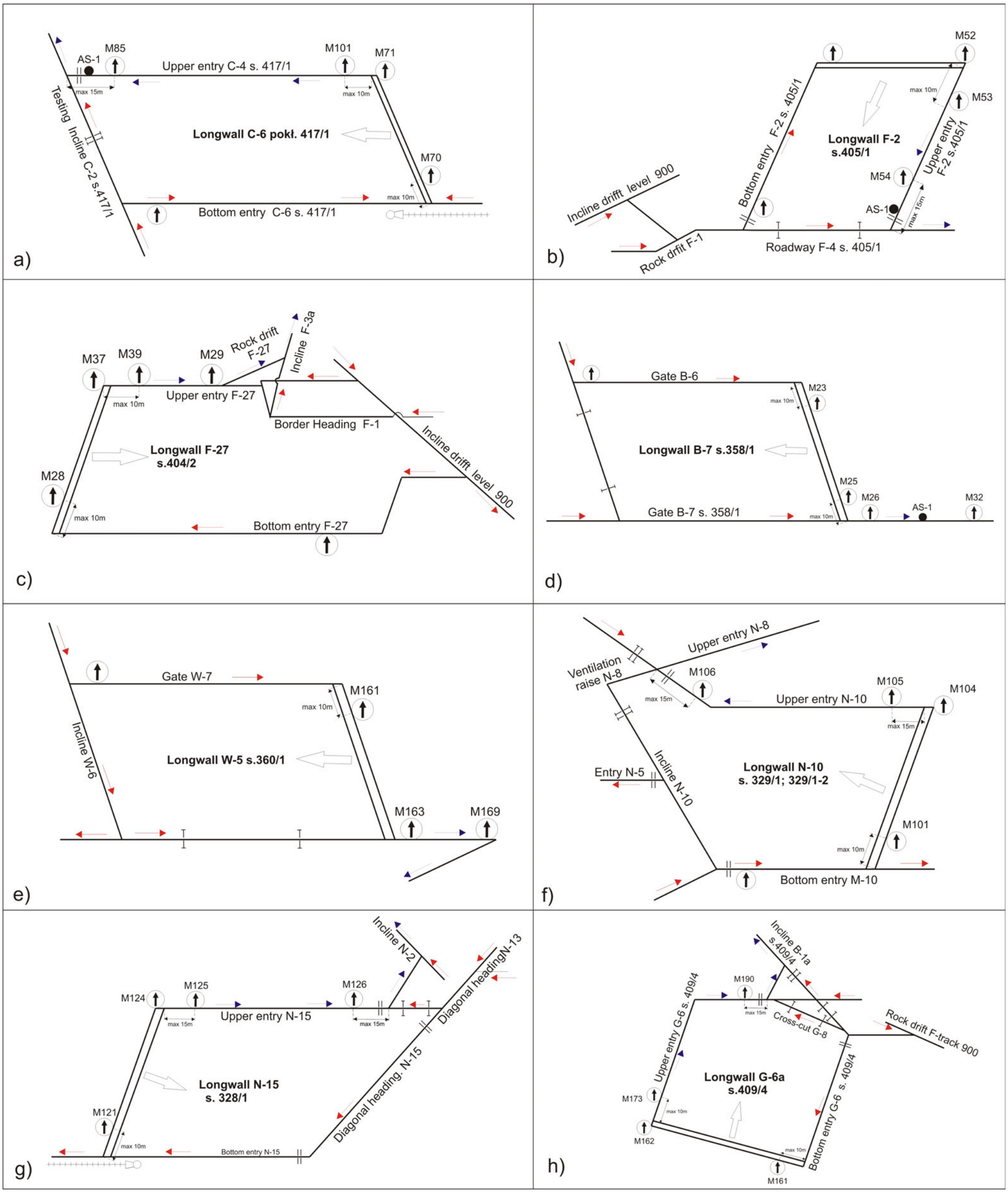

Fig. 1. Ventilation schemes of longwall that were researched:
a) longwall C-6, b) longwall F-2, c) longwall F-27, d) longwall B-7, e) longwall W-5,
f) longwall N-10, g) longwall N-15, h) longwall G-6a

In order to obtain an objective picture of the impact of longwall advance on methane-bearing capacity, a probabilistic model for the distribution of those parameters based on measurements results was used.

The basic features of examined dependences between variables based on random samples are: property of *strength* (value) and *significance* (credibility*)* of those relations. *Strength* expresses the possibility of forecasting one variable changing on the basis of the other. *Significance* informs about the possibility of determining the examined parameter when a measurement is taken in the same population. The estimation of the *strength* of relations between variables consists in examining differentiated values of examined variables and, subsequently, in calculating what part of that generally available variability can be attributed to the fact that it is common for two or more examined variables.

It must be stated that significance depends first of all on how numerous a sample is. On the basis of many samples even a very little dependence can be considered as significant while little samples do not allow to estimate the credibility of even very strong dependences. That is how a dependence giving the level of significance which informs us about the probability of error consisting in rejecting a hypothesis that dependence under research does not occur in general population is determined. That hypothesis (lack of dependence in general population) is called a zero hypothesis in statistics. In most cases we know the shape of that function and we can use it to calculate the levels of significance for different number of samples. Most of those functions are connected with a general type of function called a normal one (Statistica 8.0).

In order to determine the dependence between the value of ventilation air methane emission, methane drainage capture, absolute methane-bearing capacity and longwall advance the shape of distribution of analysed variables based on a Kolmogorow-Smirnow normality test was checked. Kolmogorow-Smirnow test for one sample uses the maximum value of difference between distribution function from a sample and assumed distribution function in order to estimate the compatibility of distribution with normal distribution. If the value of test probability is smaller than an assumed level of significance, the hypothesis that researched distribution is compatible with a normal one should be rejected. Table 2 (a-h) presents the results of normality test for absolute methane-bearing capacity (AM-BC), methane drainage capture (MDC) ventilation air methane emission (VAM) and longwall advance.

TABLE 2

Results of Kolmogorow-Smirnow normality test

a) Ściana B-7

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,85	26,66	95,00	1,00	yes
MDC, m^3/min	0,53	29,76	95,00	1,00	yes
AM-BC, m^3/min	1,28	29,91	95,00	1,00	yes
longwall advance, m/d	0,26	17,22	95,00	1,00	yes

b) Longwall C-6 (without drainge system)

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
AM-BC, m^3/min	0,09	43,68	109,00	1,00	yes
longwall advance, m/d	0,13	31,86	109,00	1,00	yes

c) Longwall F-2

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,36	22,18	84,00	1,00	yes
MDC, m^3/min	0,19	36,36	84,00	1,00	yes
AM-BC, m^3/min	0,52	28,57	84,00	1,00	yes
longwall advance, m/d	0,14	18,44	84,00	1,00	yes

d) Longwall F-27

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,26	32,41	95,00	1,00	yes
MDC, m^3/min	0,26	41,53	95,00	1,00	yes
AM-BC, m^3/min	0,46	42,05	95,00	1,00	yes
longwall advance, m/d	0,17	24,36	95,00	1,00	yes

e) Longwall G-6a

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,29	22,97	100,00	1,00	yes
MDC, m^3/min	0,35	29,86	100,00	1,00	yes
AM-BC, m^3/min	0,59	29,41	100,00	1,00	yes
longwall advance, m/d	0,09	21,24	100,00	1,00	yes

f) Longwall N-10

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,14	33,76	196,00	1,00	yes
MDC, m^3/min	0,28	27,28	196,00	1,00	yes
AM-BC, m^3/min	0,37	33,14	196,00	1,00	yes
longwall advance, m/d	0,16	20,48	196,00	1,00	yes

g) Longwall N-15

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,25	46,25	164,00	1,00	yes
MDC, m^3/min	0,36	47,76	164,00	1,00	yes
AM-BC, m^3/min	0,57	50,62	164,00	1,00	yes
longwall advance, m/d	0,20	28,27	164,00	1,00	yes

h) Longwall W-5

Particiaption	Standard error	Statistica *t*	Number of degrees of freedom *df*	Probability	Statistical significance
VAM, m^3/min	0,32	30,20	20,00	1,00	yes
MDC, m^3/min	0,13	9,75	20,00	1,00	yes
AM-BC, m^3/min	0,37	29,79	20,00	1,00	yes
longwall advance, m/d	0,14	29,75	20,00	1,00	yes

When analysing the selected results it must be stated that ventilation air methane emission, methane drainage, absolute methane-bearing capacity and longwall advance are subject to normal distribution on the assumed level of significance equal to 0.05. Therefore, there is no basis to reject a hypothesis that the mentioned parameters are subject to normal distribution. The assumed levels of significance are important as an error made during research into dependence between variables under consideration with reference to those dependences in all the population can be then determined. In further part, quantity estimation of the impact of all the factors, which can be connected by means of statistical dependence known as correlation or functional dependence, was conducted.

Table 3 (a-h) presents the calculation results of co-efficients of parameters' correlation characterizing methane hazard in researched longwalls. Numerically, the intensity of correlation of variables is usually expressed by a co-efficient of Pearson r_{xy} linear correlation co-efficient (Statistica 8.0). To determine the correlation on the basis of random samples of two variables x, y this co-efficient can be expressed by the following formula:

$$r_{xy} = \frac{\text{cov}(x,y)}{S_x S_y} \tag{2}$$

where:

cov(x,y) — covariation expressed by formula:

$$\text{cov}(x,y) = \frac{1}{n}\sum_{i=1}^{n} x_i y_i - \overline{xy} \tag{3}$$

$\bar{x}, \bar{y}$ — arithmetic averagefrom a sample siza n

S_x, S_y — standard variations of variables x and y.

This co-efficient can be both positive and negative. The sign of correlation co-efficient indicates at a dependence direction. The following scale of correlation between variables is usually assumed in statistical analysis (Statistica 8.0).

$r(x,y) = 0$	no correlation
$0 < r(x,y) < 0,1$	negligible correlation,
$0,1 < r(x,y) < 0,3$	weak correlation
$0,3 < r(x,y) < 0,5$	average correlation,
$0,5 < r(x,y) < 0,7$	high correlation,
$0,7 < r(x,y) < 0,9$	very high correlation,
$0,9 < r(x,y) < 1,0$	full correlation.

Correlation occurence based on the analysis of measurement results does not lead to statistical generalization with an identical dependence in all the population (reality). The significance test of Pearson linear correlation co-efficient is used in order to confirm such a fact. Then a zero hypothesis with a co-efficient of correlation equal to zero is verified. Such a verification is conducted on the basis of statistic t expressed by the following formula:

$$t = \frac{r(x,y)}{\sqrt{1 - r^2(x,y)}} \sqrt{n-2} \tag{4}$$

The value of statistic should not be different from zero, so critical region is determined on the basis of probability relation:

$$P(|t| \geq t_{krytyczne}) = \alpha$$

If the value of statistic *t* is greater than critical region on the assumed level of significance *α*, zero hypothesis is rejected in favour of a hypothesis that correlation co-efficient is different from zero. Table 3 presents determined values of correlation co-efficient $r(x,y)$. The next column of table 3 presents determination co-efficient, which is a measure of matching accuracy of linear dependence and informs about the quantity of the explained dependence between variables by means of linear correlation and is calculated on the basis of dependence:

$$R_d = (r(x,y))^2 \tag{5}$$

The following columns present the value of statistic *t* as well as probability and determination of statistic significance of the parameter under research:

When analysing the results presented in table 3 it must be observed that in most longwalls (B-7, F-2, F-27, G-6a) there is a high correlation between ventilation air methane emission, absolute methane-bearing capacity and longwall advance. However, in longwalls N-10 and W-5 the correlation between methane drainage capture and longwall advance is equally strong. In all other longwalls the correlation is average. In all cases, the correlations were positive, which means that with an increase in advance there is an increase in ventilation air methane emission, methane drainage capture and absolute methane-bearing capacity.

On the basis of determination co-efficient it can be stated that in cases under consideration at least in half of the results (about 50%) ventilation air methane emission, methane drainage capture and absolute methane-bearing capacity can be explained linearly by longwall advance; that statement can be assumed with probability close to 100%.

It must also be remembered that lack of high or full correlations means that parameters under research do not fully show a linear dependence; however there might be different functional correlations. Due to the complex character of phenomena occurring during mining no full correlations can be shown. However, the interpretation of the obtained results allows to come to a conclusion that the impact of longwall advance on methane emission amounts to 30 to 70% depending on the case under consideration. Therefore, other factors eg geological, which were not taken into consideration, will contribute to the level of methane hazard.

TABLE 3

Pearson correlation co-efficients between ventilation air methane emission (VAM), methane drainage capture (MDC) and absolute methane-bearing capacity (AM-BC)

a) longwall B-7

Particiaption	***r*(*x*,*y*)**	R_d	**Statistica *t***	**Probability**	**Statistical significance**
VAM, m^3/min	0,68	0,46	9,02	1,00	yes
MDC, m^3/min	0,51	0,26	5,69	1,00	yes
AM-BC, m^3/min	0,66	0,43	8,50	1,00	yes

b) Longwall C-6 (without drainge system)

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
AM-BC, m^3/min	0,58	0,34	7,45	1,00	yes

c) Longwall F-2

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
VAM, m^3/min	0,76	0,57	10,51	1,00	yes
MDC, m^3/min	0,58	0,33	6,42	1,00	yes
AM-BC, m^3/min	0,73	0,54	9,82	1,00	yes

d) Longwall F-27

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
VAM, m^3/min	0,73	0,53	10,33	1,00	yes
MDC, m^3/min	0,54	0,29	6,15	1,00	yes
AM-BC, m^3/min	0,72	0,52	10,02	1,00	yes

e) Longwall G-6a

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
VAM, m^3/min	0,63	0,40	8,07	1,00	yes
MDC, m^3/min	0,66	0,44	8,76	1,00	yes
AM-BC, m^3/min	0,71	0,51	10,08	1,00	yes

f) Longwall N-10

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
VAM, m^3/min	0,52	0,27	8,55	1,00	yes
MDC, m^3/min	0,70	0,49	13,81	1,00	yes
AM-BC, m^3/min	0,73	0,53	14,72	1,00	yes

g) Longwall N-15

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
VAM, m^3/min	0,37	0,14	5,11	1,00	yes
MDC, m^3/min	0,34	0,12	4,68	1,00	yes
AM-BC, m^3/min	0,38	0,15	5,27	1,00	yes

h) Ściana W-5

Particiaption	*r*(*x*,*y*)	R_d	Statistica *t*	Probability	Statistical significance
VAM, m^3/min	0,27	0,07	1,20	0,76	no
MDC, m^3/min	0,60	0,36	3,24	1,00	yes
AM-BC, m^3/min	0,44	0,19	2,14	0,95	yes

The presented analysis results confirm the observations of quantitative character obtained during workings in mined longwalls.

In order to determine the impact of longwall advance on methane emission, the results were presented in the form ofbox diagrams. Figures 2÷7 in the form of box diagrams present changes in absolute methane-bearing capacity in advance function for 6 selected longwalls. A box and whiskers diagram presents a central trend of each variable category in median category, value of a given variable is presented in the graph by quartiles (25. and 75. Percentile, a bigger box in the diagram) and minimal value as well as the maximum variable (whiskers in the diagram).

Longwall advance was selected as a grouping (categorised) variable and ventilation air methane emission, methane drainage capture and absolute methane-bearing capacity were selected as dependent variables. In a figure for each category, variables were shifted and located in such a way that their values do not overlap. After combining medium values, a categorized linear median diagram with percentile values and ranges of minimum and maximum variables was created.

On the basis of the presented tables and graphs it can be concluded that absolute methane-bearing capacity increases with an increase in an advance of mined longwall.

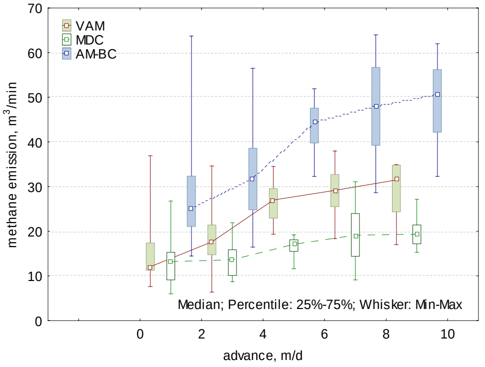

Fig. 2. Changes in methane emission in longwall B-7 depending on longwall advance

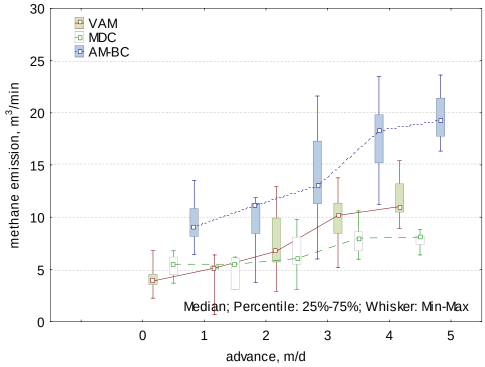

Fig. 3. Changes in methane emission in longwall F-2 depending on longwall advance

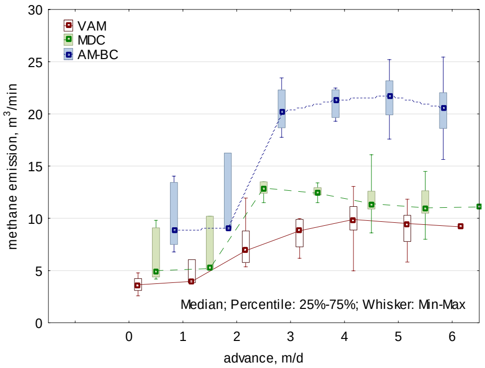

Fig. 4. Changes in methane emission in longwall F-27 depending on longwall advance

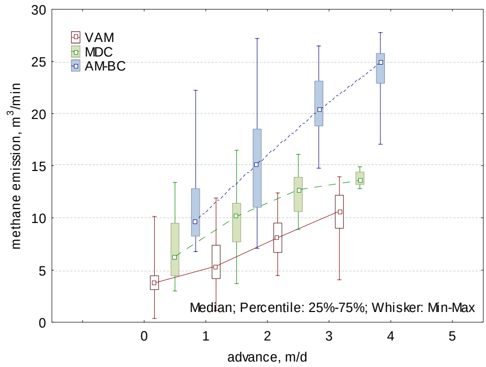

Fig. 5. Changes in methane emission in longwall G-6a depending on longwall advance

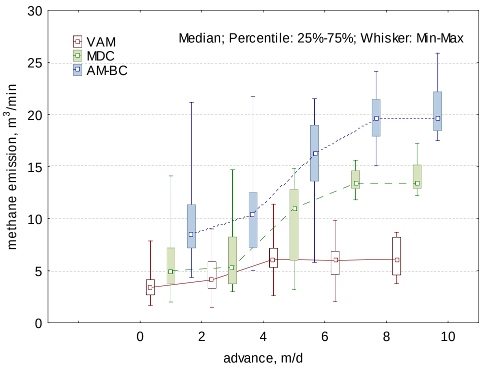

Fig. 6. Changes i methane emission in longwall N-10 depending on longwall advance

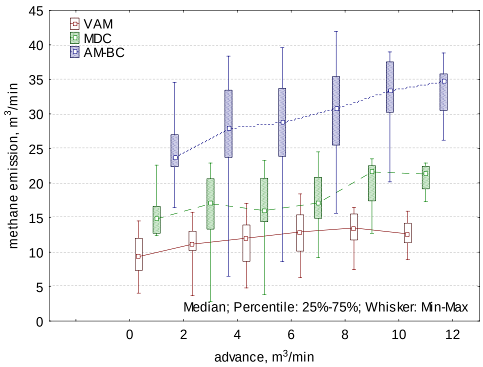

Fig. 7. Changes in methane emission in longwall N-15 depending on longwall advance

5. Impact of longwall advance on methane emission in a longwall

5.1. Estimation of linear dependence of absolute methane-bearing capacity on longwall advance

The calculation results presented in the previous section confirmed that absolute methane-bearing capacity and other longwall parameters on the assumed level of significance are compatible with a model of normal distribution. Therefore, a dependence between two variables subject to normal distribution are subjected to a linear dependence expressed by a function of linear regression of kind I.

$$y = A + B \cdot x \tag{6}$$

where:

A — free term – estimator of linear regression co-efficient,

B — regression parameter –estimator of direction co-efficient of linear regression.

Co-efficients A and B are determined by means of the method of the smallest squares from dependence:

$$B = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y}}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{7}$$

$$A = \overline{y} - B\overline{x} \tag{8}$$

Standard variation of estimators of linear regression is determined in the following way:

$$S_B = \sqrt{\frac{\sigma_r^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \tag{9}$$

$$S_A = \sqrt{\frac{\sigma_r^2 \sum_{i=1}^{n} x_i^2}{n\sum_{i=1}^{n}(x_i - \bar{x})^2}} \tag{10}$$

where: σ_r^2 is a remainder variation in the method of the smallest squares (Statistica 8.0).

Standard variations of estimators are a measure of a value of random errors while estimating by means of determined estimators. On the basis of the formulae above linear regression co-efficients were determined by means of the method of the smallest squares. The calculation results of dependence of absolute methane-bearing capacity on longwall advance are presented in the following figures. In figures 8÷13 a graph of spread of values of absolute methane-bearing capacity depending on advance for 6 selected longwalls is presented. An equation which describes the dependence in changes in absolute methane-bearing capacity on longwall advance is also presented in the figure. Region which belongs to 95% of

$$q = 14{,}97 + 1{,}20v \tag{11}$$

where:

- q — longwall absolute methane-bearing capacity, m^3/min,
- v — longwall advance, m/day.

TABLE 4

Matching values of co-efficients of linear regression equation

Long-wall	**Co-effi-cient**	**Value of co-effi-cient**	**Standard error**	**Statis-tica *t***	**Proba-bility**	**Lower confidence limit**	**Upper confidence limit**	**Contribu-tion of explained variation R^2**	***r***
B-7	A	3,292	0,108	30,583	1,000	3,079	3,504	0,260	0,510
C-6		11,094	0,422	26,304	1,000	10,260	11,928	0,374	0,612
F-2		15,929	0,537	29,644	1,000	14,867	16,992	0,226	0,475
F-27		12,876	0,559	23,020	1,000	11,772	13,980	0,275	0,524
G-6a		9,724	0,347	28,028	1,000	9,041	10,407	0,261	0,510
N-10		27,545	0,668	41,241	1,000	26,230	28,861	0,031	0,176
N-15		9,973	0,513	19,433	1,000	8,922	11,024	0,118	0,343
W-5		3,292	0,108	30,583	1,000	3,079	3,504	0,260	0,510
	Average	14,97							

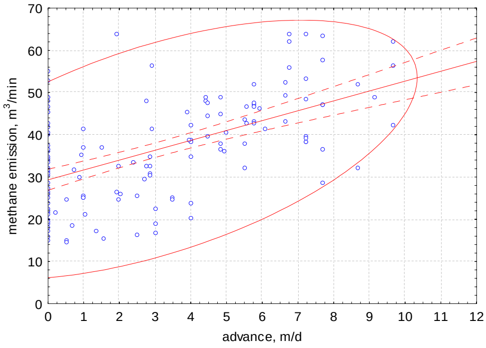

Fig. 8. Change in absolute methane-bearing capacity in advance function of longwall B-7

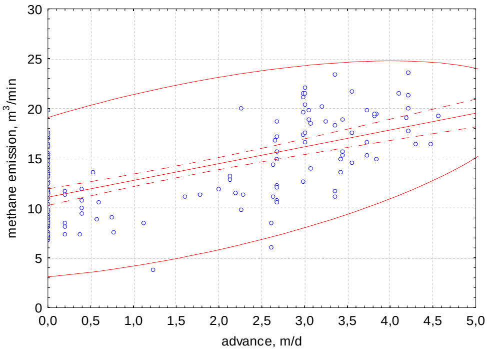

Fig. 9. Change in absolute methane-bearing capacity in advance function of longwall F-2

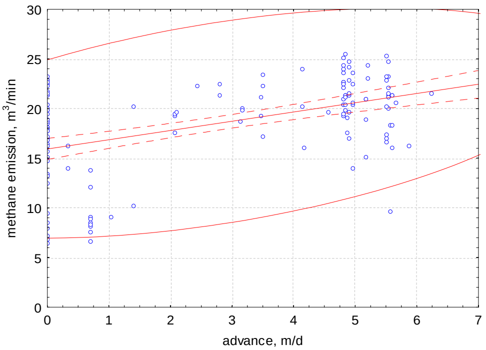

Fig. 10. Change in absolute methane-bearing capacity in advance function of longwall F-27

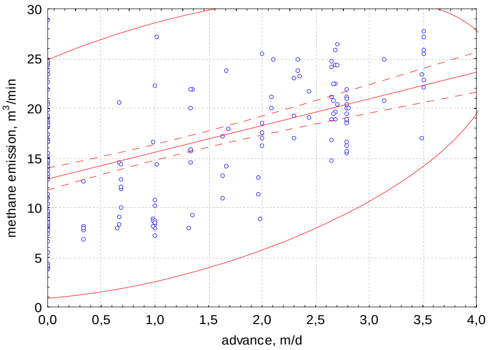

Fig. 11. Change in absolute methane-bearing capacity in advance function of longwall G-6a

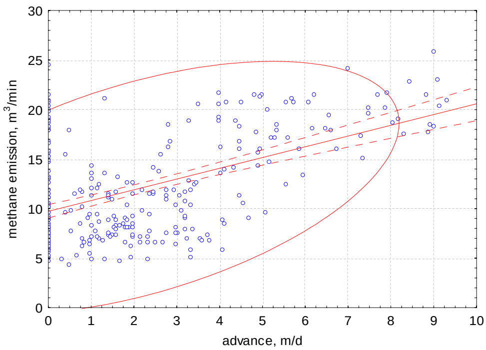

Fig. 12. Change in absolute methane-bearing capacity in advance function of longwall N-10

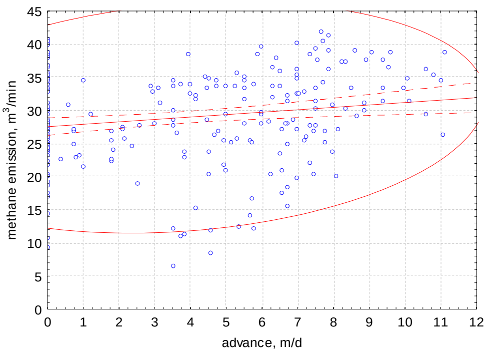

Fig. 13. Change in absolute methane-bearing capacity in advance function of longwall N-15

TABLE 4. continued

Long-wall	Co-effi-cient	Value of co-effi-cient	Standard error	Statis-tica *t*	Proba-bility	Lower confidence limit	Upper confidence limit	Contribu-tion of explained variation R^2	*r*
B-7	B	2,337	0,299	7,810	1,000	1,746	2,929	0,308	0,555
C-6		0,224	0,030	7,547	1,000	0,165	0,282	0,260	0,510
F-2		1,688	0,188	8,990	1,000	1,317	2,060	0,374	0,612
F-27		0,931	0,147	6,342	1,000	0,641	1,221	0,226	0,475
G-6a		2,687	0,334	8,055	1,000	2,029	3,346	0,275	0,524
N-10		1,086	0,106	10,229	1,000	0,877	1,294	0,261	0,510
N-15		0,364	0,131	2,790	0,994	0,107	0,622	0,031	0,176
W-5		0,273	0,141	1,932	0,936	-0,016	0,563	0,118	0,343
	Average	1,199							

5.2 Estimation of non-linear dependence of absolute methane-bearing capacity on longwall advance

Due to a low contribution of explained linear variation of advance dependence on methane emission in a longwall, non-linear dependence of longwall advance on methane emission was estimated. In figures 14÷19 a graph of spread of absolute methane-bearing capacity depending on longwall advance was presented. The dependence between two variables subject to normal distribution is presented by non-linear dependence expressed by regression function of kind II:

$$y = A + B \cdot \sqrt{x} \tag{12}$$

where: A and B — estimators of non-linear regression co-efficients.

Co-efficients A and B are determined by non-linear method of the smallest squares. In order to estimate co-efficients A and B in equation (12) a regression model, in which the dependence between independent variables and a dependent variable is determined, was used. The procedure contained in programme Statistica 8.0, which uses Levenberg-Marquardt algorithm (non-linear method of the smallest squares) was used.

When using the function of the smallest squares in order to estimate the parameters it is not necessary to calculate (or approximate) second partial derivatives. Instead of that, with each step, algorithm solves a set of linear equations to calculate gradients, which is comparatively easy and quick (compared to other optimalisation techniques) as far as calculation is concerned. Levenberg-Marquardt (LM) method is an expansion and modification of Gauss-Newton method to solve a non-linear problem by means of the method of the smallest squares.

Figures 14÷19 also present an equation, which describes the dependence of changes in absolute methane-bearing capacity on longwall advance. It can be concluded that dependences (presented graphically) describe well changes in parameters under consideration.

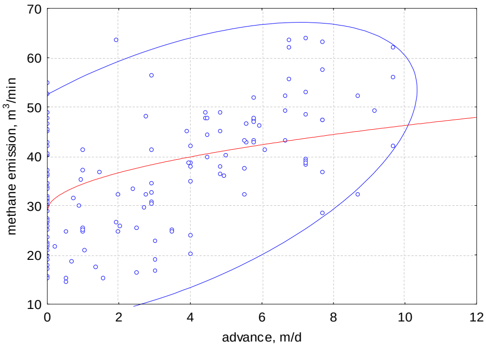

Fig. 14. Change in absolute methane-bearing capacity in advance function of longwall B-7

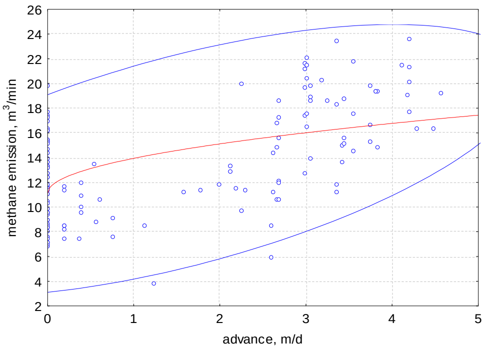

Fig. 15. Change in absolute methane-bearing capacity in advance function of longwall F-2

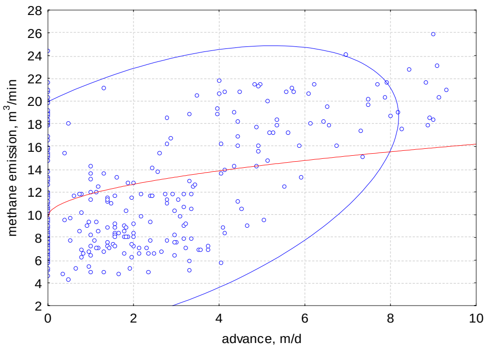

Fig. 16. Change in absolute methane-bearing capacity in advance function of longwall N-10

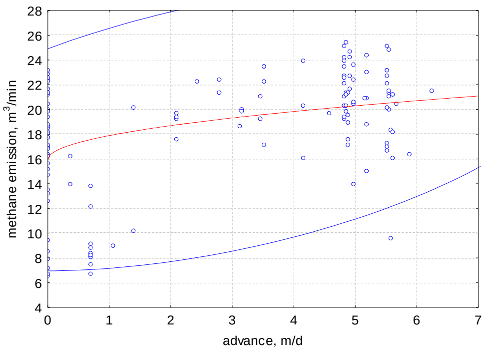

Fig. 17. Change in absolute methane-bearing capacity in advance function of longwall F-27

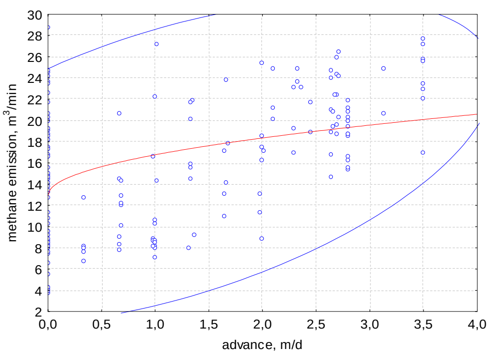

Fig. 18. Change in absolute methane-bearing capacity in advance function of longwall G-6a

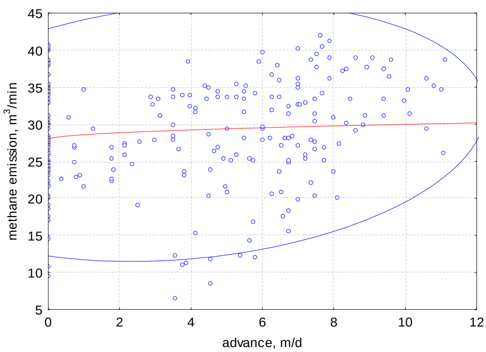

Fig. 19. Change in absolute methane-bearing capacity in advance function of longwall N-15

Table 5 presents graphically determined non-linear regression co-efficients. On the basis of data from table 5 an equation describing a dependence of absolute methane-bearing capacity in a longwall on longwall advance in the following form can be presented:

$$q = 6{,}21 + 6{,}73\, v^{0{,}5} \tag{13}$$

where:

q — longwall absolute methane-bearing capacity, m^3/min,

v — longwall advance, m/day

When comparing co-efficient R^2 of contribution of explained variation in tables 4 and 5, it can be concluded that non-linear dependence explains better the results obtained during mining measurements. Myszor suggests a similar dependence of methane emission on output.

TABLE 5

Matching values of co-efficients of non-linear regression equation

Long-wall	Co-effi-cient	Value of co-effi-cient	Standard error	Statis-tica *t*	Prob-ability	Lower confidence limit	Upper confidence limit	Contribu-tion of explained variation R^2	*r*
B-7	A	13,097	3,085	4,246	1,000	6,973	19,222	0,441	0,664
C-6		1,151	0,424	2,714	0,992	0,310	1,993	0,323	0,569
F-2		4,523	1,175	3,850	1,000	2,187	6,859	0,502	0,709
F-27		6,251	1,191	5,247	1,000	3,885	8,616	0,582	0,763
G-6a		1,616	1,601	1,009	0,685	-1,561	4,792	0,510	0,714
N-10		2,113	0,798	2,647	0,991	0,539	3,687	0,491	0,700
N-15		18,928	2,042	9,270	1,000	14,896	22,960	0,132	0,364
W-5		1,981	4,103	0,483	0,365	-6,606	10,568	0,206	0,454
	Average	6,208							
B-7	B	12,630	1,468	8,606	1,000	9,716	15,544	0,441	0,664
C-6		1,485	0,207	7,182	1,000	1,075	1,895	0,323	0,569
F-2		6,727	0,735	9,152	1,000	5,265	8,189	0,502	0,709
F-27		6,710	0,586	11,447	1,000	5,546	7,874	0,582	0,763
G-6a		11,645	1,148	10,141	1,000	9,367	13,924	0,510	0,714
N-10		6,000	0,438	13,706	1,000	5,137	6,863	0,491	0,700
N-15		4,275	0,857	4,988	1,000	2,582	5,967	0,132	0,364
W-5		4,398	1,980	2,221	0,961	0,253	8,543	0,206	0,454
	Average	6,734							

6. Conclusions

On the basis of the research conducted it can be concluded that together with longwall advance there is an increase in methane concentration as well as longwall absolute methane-bearing capacity at the outlet from longwall panel. Methane emission to longwalls differs greatly both daily, weekly and during mining of the whole longwall panel. On that basis statistical dependences between parameters can be determined as well as which factor has a significant impact on methane emission. The conditions of safe mining can be determined for a particular methane emission.

The research conducted shows that in most longwalls there is a high correlation between ventilation air methane emission, absolute methane-bearing capacity and longwall advance. In all those cases, correlations are positive, which means that together with an increase in advance there is an increase in ventilation air methane emission, methane drainage capture and longwall advance.

On the basis of determination co-efficient it can be concluded that in the longwalls under research at least half of the results (about 50%) of changes in ventilation air methane emission, methane drainage capture and absolute methane-bearing capacity can be explained by a linear dependence on longwall advance and this conclusion can be drawn with probability close to 100%. When comparing co-efficient R^2 of contribution of explained variation in table 4 and 5 it can be concluded that non-linear dependence explains better the results obtained during mining measurements.

The interpretation of results allows to decide that longwall advance allows for methane emission in 30 to 70% depending on a case under consideration. Therefore, other factors eg geological that were not taken into consideration will contribute to the level of methane hazard.

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