e-ISSN 2719-3306 Mining Machines, 2022, Vol. 40 Issue 3, pp. 149-157

https://doi.org/10.32056/KOMAG2022.3.4

Analysis of one-day forecasts of the maximum methane concentration in a tailgate of a longwall ventilated with U system - a case study

Received: 24.09.2022

Accepted: 03.10.2022

Published online: 11.10.2022

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Abstract:

Methane that is released into the mine atmosphere poses a threat to the miners working there. Methane at concentrations of 5-15% by volume in air is an explosive gas. It has caused devastating explosions in mines all over the world. Therefore, in methane mines, concentration of methane in the face and in the entire mine is controlled through well-designed ventilation system. This system controls concentration of methane in the mine atmosphere and in the rock mass as well as in the mine goafs. The article's main objective includes a presentation of a forecast for maximal methane concentration in the determined time interval. Sensors were installed in the gate draining the air from longwall: up to 10 m in front of the longwall and at the roadway exit. Both forecasts were made using prognostic equations, using the measurement data in the ventilation roadway of one of the longwalls at the JSW S.A. mine.

Keywords: methane, maximum methane concentration, methane concentration forecasts, methane concentration sensors

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1. Introduction

Coal Mine Methane (CMM) is a gas released from coal seams and the surrounding rock layers.

Methane released into the atmosphere is a significant greenhouse gas contributing to climate change worldwide. Currently in the US it is assumed that the global warming potential (GWP) of methane is 25 times greater than that of carbon dioxide for 100 years [1]. However, the literature shows GWP values of 21, 23, 25 and even 28. The US Environmental Protection Agency (USEPA) estimates that methane from coal mines is responsible for 8% of global methane emissions caused by human activity [2].

Experience from the last 20 years shows that the most common methane GWP value is 72. The lifespan of methane in the atmosphere is estimated at about 7 years.

Methane released into the mine atmosphere poses a threat to the miners working in the mines. Methane at concentration 5-15% in air is explosive. In the long history of coal mining industry, methane has been the cause of devastating explosions in many mines around the world.

A one-day forecasts of the maximum concentration of methane in the sensors located in near-longwall roadway, which removes used air from the longwall: up to 10 m ahead of the longwall and at the roadway exit is presented.

2. Literature review

Methane explosion hazard is one of the most common threats in the Polish coal mining industry [3, 4]. The report prepared by the Mining Department of the State Mining Authority [5] for 2020, which presents data on methane and outburst hazards in Polish underground mining industry, shows that in 2020, 77.1% of coal production in Poland came from methane deposits. So far, the highest percentage of coal extracted from methane seams was in 2017 - 79.5%.

Methane in Polish coal deposits occurs in three forms [6, 7]:

- as free methane (in fractures, macropores and mesopores),
- coal bound methane (physical and chemical sorption),
- methane dissolved in water.

During the coal seam mining, methane flows into the mine atmosphere from the mined coal seam and from the roof and floor rocks. The carriers of methane in the floor and roof rocks are coal seams and layers that are not suitable for mining as well as porous waste rocks, mainly sandstones. In waste rocks, methane occurs almost entirely as free gas, not adsorbed. Mining exploitation causes the outflow of methane into the mine atmosphere from the mined seam and from the rocks surrounding it.

The method of ventilation of the longwall area has a significant impact on methane hazard and the distribution of methane concentration in workings [8, 9, 10, 11]. This publication concerns a ventilated longwall in the U system, i.e. the ventilation air stream flows from the ramp along the head entry towards the longwall, then ventilates the longwall and then, through the ventilation roadway, flows to the ramp. The direction of air flow in the head entry and tailgate are opposite. It is a typical method of ventilating the areas of non-methane and methane longwalls with low and medium methane content. The ventilation methane capacity, i.e. the stream of methane in the air stream in the longwall area, cannot exceed 20 m^3CH_4/min [12]. If technical measures do not allow to obtain ventilation methane capacity not exceeding the above-mentioned level, it is necessary to use ventilation systems other than U, e.g. Y or W [13, 14].

In order to protect the personnel working in longwalls against the threats resulting from the presence of methane in the seam and surrounding rocks, a methane concentration should be forecast prior to the of exploitation of the seam in a given longwall. The forecast prepared at the Central Mining Institute in Katowice [15] is the most widely used in Poland, but other forecasts are also used. Many methods of methane concentration have been developed in the world. They are

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adapted to the natural conditions of a specific coal basin. Examples can be found in the literature, e.g. [16-19].

In the Polish coal mining industry, the last thirty years have brought very significant changes in the equipment with telemetric systems for measuring physical and chemical parameters of the mine atmosphere [20, 21]. One of the functions of these systems in methane mines is the measurement of methane concentration in places specified by mining regulations. The system has a measuring, recording and archiving function, informing, warning and switching off the electric current. Due to the deeper understanding of the phenomenon of methane emission to workings, the function of recording and archiving measurement data in automatic measurement systems plays an essential role. These data can be derived outside the telemetry system and processed at any time, which allows for their comprehensive analysis and inference in order to better understand the methane emission phenomenon and use it to improve work safety in mining [22-24]. In highly methane longwalls, more sensors are used than required by law. Additional sensors are placed in the locations where increased methane concentrations may occur.

The article [24] describes a set of model parameters for one-day forecasts of the mean and maximum methane concentration at the outlet of the workings that discharge used air from the longwall. The research work conducted on applying these models to forecast the average methane concentration at the outlets from the longwall ventilation workings confirmed their accuracy [25, 26]. This article presents an attempt to use these models to forecast the maximum concentration of methane in a roadway discharging used air from the longwall, at the location of the methane concentration sensor at a distance of up to 10 m from the face of the longwall and at the exit of the ventilation roadway (10-15 m before the crossing with another workings with air supply). The air stream in these places is almost the same, however, the degree of homogeneity of the air-methane mixture at the exit of the roadway and at a distance of up to 10 m in front of the longwall is different. It is caused by turbulent air flow in the workings and the phenomenon of diffusion.

An important issue is demethanization, i.e. capturing methane directly from the rock mass and discharging it to the surface via a pipeline system. The negative pressure in this system is often caused by suction devices located on the surface. A large part of such methane is processed economically, e.g. to power electricity generators or to generate heat.

Proper management of methane from hard coal deposits will contribute to its economic use, and at the same time will reduce the greenhouse effect associated with the release of methane into the atmosphere [27, 28].

3. Materials and Methods

Data on methane concentration are archival data and come from automatic measurements of methane concentration in one of the longwalls of Jastrzębska Spółka Węglowa S.A.

Using the software of the methane concentration measuring system, the measurement data are converted into a text form and transfer out the measuring system in a tabular form (Table 1).

Table 1. Sample measurement data of methane concentration in one of the longwalls of JSW S.A.

Start time	Measurement	Duration	Statuses
12.04.2022 15:05:24	1.2%CH4	0:00:01	
12.04.2022 15:05:05	1.3%CH4	0:00:19	
12.04.2022 15:04:32	1.4%CH4	0:00:33	
12.04.2022 15:04:20	1.3%CH4	0:00:12	
12.04.2022 15:04:12	1.2%CH4	0:00:08	

In the above entry, in the first column of Table 1 (Start Time), the date of measurement and the start time of the measurement of methane concentration are recorded, with the value given in

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the second column, entitled Measurement. Measured concentration in the Measurement column is given with an accuracy of 0.1%, which corresponds to the measurement accuracy of the methane sensor. The next column, Duration, defines the time of occurrence of the methane concentration with the value given in the previous column with an accuracy of 1 second. In the Status column, there are notes regarding extraordinary states, e.g. checking the accuracy of measurements, exceeding the set concentration threshold, etc.

On the basis of the data prepared in this way, using the PROGMET program developed at the Silesian University of Technology, the average, minimum and maximum values of methane concentration are calculated in a given day, with the day being counted from a given hour, not from 00:00:00. In the data contained in the presented article, the calculation day is the period from 06:00:00 on the current day to 06:00:00 on the following day. .

With the output data prepared in such a way, the forecast values of methane concentration are calculated using the models presented in the paper [24].

4. Results – characteristics and interpretation of measurement data

The measurement data covers 195 days, with 194 one-day forecasts, as one-day forecast uses the measurement values of the previous day.

Fig. 1 shows maximum methane concentrations in a given day, calculated on the basis of the measurements of the sensor located in the ventilation roadway up to 10 m in front of the longwall and the sensor located 10-15 m before the exit from this roadway.

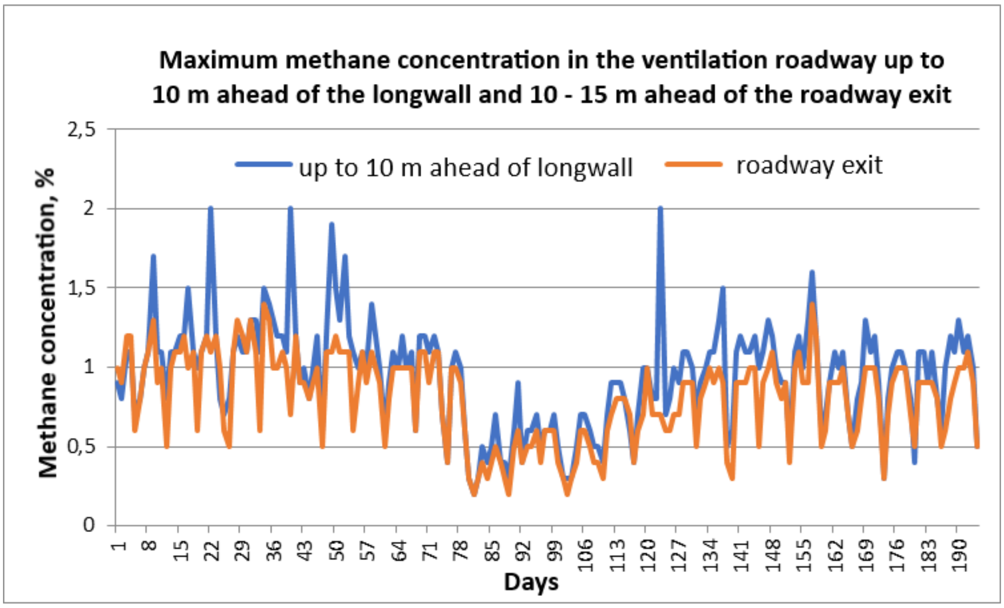

Fig. 1. Maximum measured methane concentration in the places where the sensors are located in the ventilation roadway

In Fig. 1 it can be seen that on most observation days the maximum concentration in the ventilation passage up to 10 m in front of the face of the wall is higher than at the exit of the ventilation roadway. Characteristic parameters of average methane concentrations found with sensors in the discussed places are presented in Table 2.

Table 2. Statistical parameters of the maximum concentrations of methane found in the ventilation pavement at a distance of 10 m in front of the wall and at the roadway exit, calculated for the entire observation period

Parameter	Up to10 m ahead of longwall	At the roadway exit
average, %CH_4	0.95	0.81
median, %CH_4	1.00	0.90
percentile 0,9, %CH_4	1.30	1.10
minimum, %CH_4	0.20	0.20
maximum, % CH_4	2.00	1.40
standard deviation, %CH_4	0.34	0.28
variation factor, %	35.61	34.10
range of methane conc., %CH_4	1.80	1.20
sum of max. conc., %CH_4	184.10	157.60

Values of eight parameters of methane concentration calculated for the readings of the methane concentration sensor located up to 10 m in front of the longwall face are higher than at the exit of the ventilation roadway. And so the mean value is higher by 0.14%, the median by 0.10%, the 0.9 percentile by 0.20% CH_4, the maximum value by 0.6%, the range of methane concentration is greater by 0.6%, the standard deviation is greater by 0.06%, and the coefficient of variation in the methane concentration is greater by 1.51%

The standard deviation and the variation factor testify the high variability of the methane emission to mine workings related to coal seam mining.

Only the minimum values of the maximum concentrations of methane in both considered places are equal and amount to 0.2%.

The prognostic equations developed for the outlet from the ventilation roadway were used to predict the concentration of methane up to 10 m in front of the longwall. To assess whether these equations give satisfactory results, methane concentration at the exit of the roadway were also forecasted to compare the forecast results in both of places.

Fig. 2 and 3 show the graphs of the maximum measured and forecasted methane concentrations in both of the above-mentioned places, and Tables 3 and 4 contain their statistical parameters.

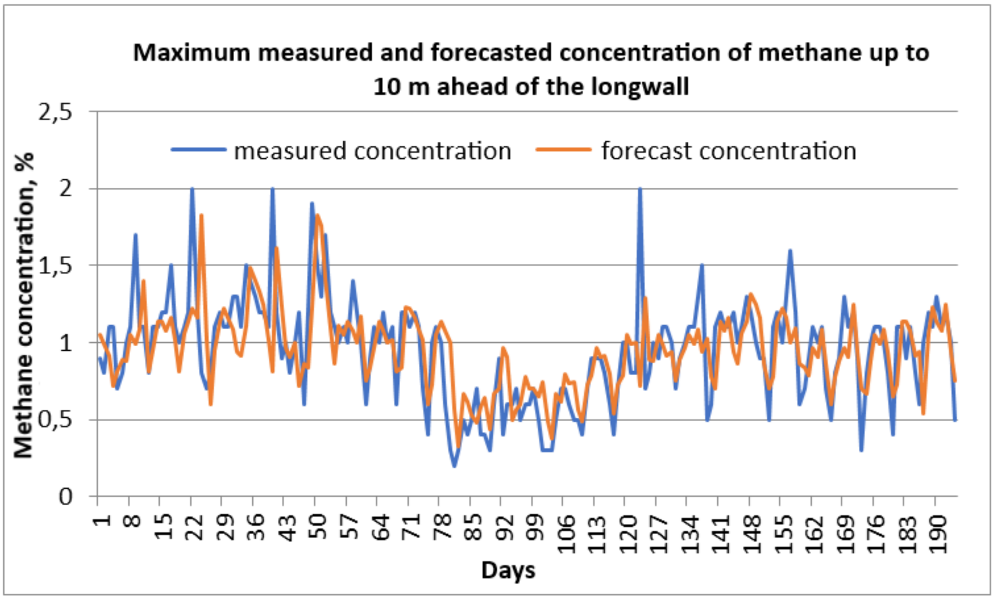

Fig. 2. Maximum measured and forecasted methane concentration in the tailgate at a distance of up to 10 m from the longwall face

Table 3. Statistical parameters of the maximum measured and forecast methane concentrations in the roadway within 10 m from the longwall face

Parameter	Up to 10 m ahead of longwall - measurement	Up to 10 m ahead of longwall - forecast	Difference
average, $\%CH_4$	0.95	0.95	0
median, $\%CH_4$	1.00	0.96	-0.04
percentile 0.9, $\%CH_4$	1.30	1.23	-0.07
minimum, $\%CH_4$	0.20	0.33	0.13
maximum, $\% CH_4$	2.00	1.83	-0.17
standard deviation, $\%CH_4$	0.34	0.25	-0.09
variation factor, %	35.61	26.22	-9.39
range of methane conc., $\%CH_4$	1.80	1.50	-0.30
sum of max. conc., $\%CH_4$	184.10	183.91	-0.19

The average maximum methane concentration, calculated on the basis of measurements taken over 194 days, is 0.95% CH_4, also calculated from the forecasts is 0.95% CH_4. However, this does not mean that all measured and forecast values are close to each other. The medians already differ, but the median calculated on the basis of the measurements is higher than the median calculated for the forecasts. The forecast has lower values of the following further statistical parameters: 0.9 percentile, maximum, standard deviation and coefficient of variation, methane concentration range. Only the projected minimum value is higher than the measurement value, which of course limits the variations range of the forecast maximum methane concentration (the measurement range of methane concentration variations was 1.8% CH_4, and the forecasted 1.5% CH_4). The sum of the maximum methane concentrations calculated on the basis of the measurements is also higher than the sum of the forecast maximum concentrations, although the difference is surprisingly small. The reduced range of variability of the forecasted maximum concentrations is also evidenced by the much lower value of the variation factor of the forecast methane concentrations (26.22%) in relation to the variation factor of the measured values of the maximum methane concentration (35.61%).

Nex the results of measurements and forecasts of the maximum concentration of methane at the exit of the ventilation roadway (10-15m ahead of the connection with another active roadway).

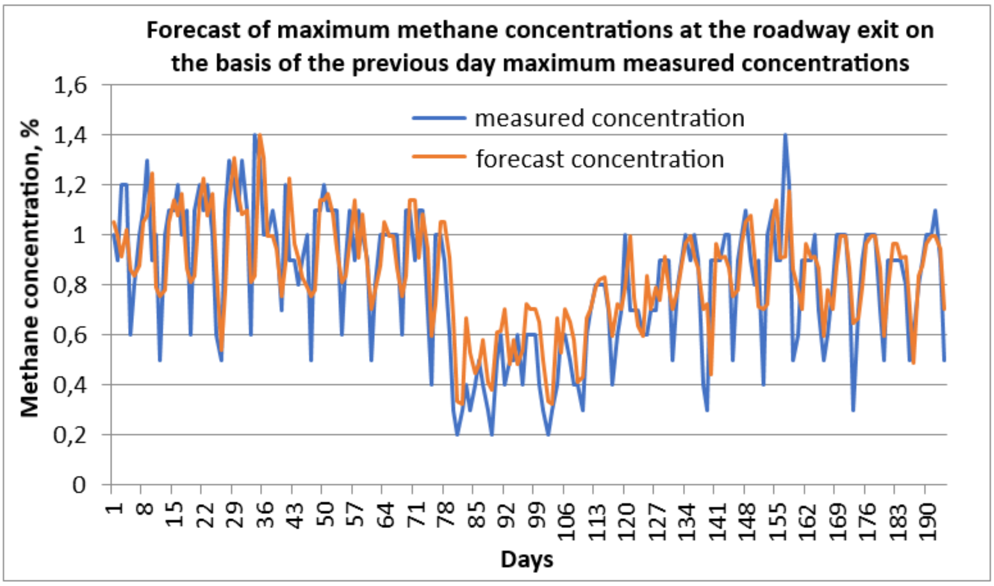

Fig. 3. Maximum measured and forecasted methane concentration in the tailgate at the roadway exit

Table 4. Statistical parameters of the maximum measured and forecasted methane concentration at the exit of the ventilation roadway

Parameter	At the roadway exit - measurement	At the roadway exit – forecast	Difference
average, $\%CH_4$	0.81	0.84	0.03
median, $\%CH_4$	0.90	0.86	-0.04
percentile 0.9, $\%CH_4$	1.10	1.14	0.04
minimum, $\%CH_4$	0.20	0.33	0.13
maximum, % CH_4	1.40	1.40	0.00
standard deviation, $\%CH_4$	0.28	0.21	-0.07
variation factor, %	34.10	25.01	-9.09
range of methane conc., $\%CH_4$	1.20	1.07	-0.13
sum of max. conc., $\%CH_4$	157.60	163.32	5.72

Mean value of the maximum concentration of methane, calculated on the basis of measurements taken over 194 days, is 0.81% CH_4, while the calculated value based on prognostic equations is 0.84% CH_4, i.e. it is higher by 0.03% CH_4. The difference between the medians is -0.04% CH4, i.e. the median of measurement data is higher. The difference between the 0.9 percentiles is 0.04%, which is not much overestimated in relation to the measured one. The minimum forecast value of the maximum methane concentration is by 0.13% higher than the measured value, and the maximum values do not differ. The standard deviation of the forecasts is lower than the standard deviation of the measurements by -0.07% CH4, while the variation factor of the forecasts is lower than that calculated from measurements by -9.09%.

The forecasts have a slightly narrower range of variation in relation to the measurements, and the difference is -0.13% CH4.

Taking into account the entire observation period of the prognostic parameters, it can be concluded that they do not differ much, and the forecast is slightly overestimated. The sum of the values of the forecast methane concentrations is 5.72% CH4 higher than the sum of the measured values.

Table 5 presents differences between the measurement parameters and the projected maximum methane concentration in the ventilation pavement at a distance of up to 10 m in front of the wall and at the pavement outlet, at a distance of 10-15 m from the intersection with another excavation.

Table 5. Differences between the statistical parameters of the maximum methane concentration in the ventilation roadway up to 10 m ahead the longwall face of the and at a distance of 10-15 m from the intersection with another excavation

Parameter	Differences 10 m ahead the longwall	Differences from the intersection
average, $\%CH_4$	0	0.03
median, $\%CH_4$	-0.04	-0.04
percentile 0.9, $\%CH_4$	-0.07	0.04
minimum, $\%CH_4$	0.13	0.13
maximum, % CH_4	-0.17	0.00
standard deviation, $\%CH_4$	-0.09	-0.07
variation factor, %	-9.39	-9.09
range of methane conc., $\%CH_4$	-0.30	-0.13

Negative values mean that the statistical parameters of the maximum methane concentration forecasts are lower than their values for the measured data.

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The comparison of the measurement parameters and the forecast maximum methane concentration shows that the differences in both considered places are small, and therefore the forecast equations developed for the exit from the roadway may be helpful in practice for the assessment of the methane hazard in close proximity (up to 10 m) to the longwall exit to the ventilation roadway.

5. Conclusions

Possibility of using the models for one-day maximum methane concentration forecast, developed for the ventilation roadway outlet to forecast the maximum concentration of methane in the given roadway at the location of the methane concentration sensor at a distance of up to 10 m from the face of the longwall was presented. The parameters of the forecast models were taken from paper [24]. Comparison of the statistical parameters concerning the forecasts of methane concentration in the above-mentioned places shows that the accuracy of the forecasts of the maximum methane concentrations in both places are similar, with a slightly greater error in the forecast of methane concentration in the roadway at a distance of up to 10 m ahead of the longwall. Further research work to analyze methane concentration forecasts at the longwall outlet using the forecast equations, presented in paper [24], enabled their practical use as well as development of new forecast functions regarding the maximum concentration of methane in the roadway, in the immediate vicinity of the outlet from the longwall.

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