Management Systems
in
Production Engineering

2022, Volume 30, Issue 4, pp. 342-347

Date of submission of the article to the Editor: 05/2022
Date of acceptance of the article by the Editor: 10/2022

DOI 10.2478/mspe-2022-0043

ANALYSIS OF FORECASTED METHANE CONCENTRATION AT THE TOP GATE OF A WALL VENTILATED BY MEANS OF THE "U" SYSTEM. CASE STUDY

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Abstract:
The release of methane into the mine atmosphere poses a threat to the miners. Methane is an explosive gas at concentrations of 5-15% in air by volume and throughout the history of coal mining has been the cause of devastating explosions in mines around the world. For these reasons, in methane coal mines, the concentration of methane emitted from the coal face and the entire mine is controlled by means of a well-designed ventilation system, a system controlling the concentration of methane in the mine atmosphere and a system for methane drainage of the rock mass and goafs. The presented article concerns the forecast of the average concentration of methane on a given day, in the places of sensors located in the longwall roadways of discharge air exhausted from the longwall: up to 10 m in front of the wall and at the outlet of the roadway. Both forecasts were made using the prognostic equations on the basis of measurement data concerning the ventilation roadways of one of the longwalls at JSW SA.

Key words: *methane, average concentration of methane, forecast, methane concentration sensors, PROGMET program*

INTRODUCTION

Methane in coal mines (CMM) is a gas released from coal seams and the surrounding rock strata.

Methane emitted to the atmosphere is a significant greenhouse gas contributing to climate change worldwide. The USA currently assumes that the global warming potential (GWP) of methane is 25 times greater than that of carbon dioxide over 100 years [1]. However, in the literature, one can find values equal to 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].

On a 20-year scale, the most often assumed GWP value of methane is 72.

The "life" of methane in the atmosphere is estimated at about 7 years.

The methane emitted into the mine atmosphere poses a threat to the miners working in the mines. Methane is an explosive gas at concentrations of 5-15% in air by volume and throughout the history of coal mining has been the cause of devastating explosions in mines around the world.

The presented work concerns the forecasted average concentration of methane on a given day in the locations where sensors are placed at the roadway (main gate) of the discharge air exhausted from a longwall: up to 10 m in front of the wall and at the outlet of roadway.

REVIEW OF THE LITERATURE

One of the most common threats in Polish coal mining is the methane hazard [3, 4]. The report prepared by the Mining Department of the Higher Mining Office [5] for 2020, which presents data on the development of methane and outburst hazards in Polish underground mining, shows that in 77.1% of coal production in Poland came from methane deposits in 2020. So far, the highest percentage of coal extraction from methane deposits was reported in 2017 and accounted for 79.5%.

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

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

During the exploitation of the coal seam, methane is flowing into the mine atmosphere from the mined coal seam and from the roof and floor rocks. The carriers of methane in the floor and ceiling rocks are coal seams and strata not suitable for exploitation, porous waste rocks, and above all sandstones. In waste rocks, methane is almost entirely free, not absorbed gas. Mining exploitation causes the outflow of methane into the mine atmosphere from the mined seam and from the rocks surrounding the mining excavation.

The method of ventilating the longwall area has a significant impact on the degree of methane hazard and the distribution of methane concentration in roadways [8, 9, 10, 11]. This publication concerns a longwall ventilated by means of the “U” system, i.e., the ventilation air stream flows from the inclined drift along the bottom gate towards the longwall, then ventilates the wall and then, through the ventilation roadway, flows to the inclined drift. The directions of air flow in the bottom gate and top gate are opposite. It is a typical method of ventilating the non-methane and methane longwall areas of low and medium methane content. The ventilation methane-bearing capacity of the longwall area cannot exceed 20 m^3 CH_4/min [12]. In the case of higher methane bearing capacity, it is necessary to use ventilation systems other than U, e.g., Y or W [13, 14].

In order to adequately protect the mining crews working in the longwalls against the hazards resulting from the presence of methane in the seam and the surrounding rocks, prior to the commencement of operating on a specific longwall, a longwall methane content forecast should be performed. The most widely used forecast in Poland is the forecast prepared at the Central Mining Institute in Katowice [15]. There have been many methods of forecasting the methane bearing capacity developed in the world. As a rule, they are adapted to the natural conditions of a specific coal basin. Examples can be found in the literature, e.g. [16, 17, 18, 19].

In the Polish coal mining industry, the last three decades have brought significant changes in equipping mines with telemetric systems for measuring physical and chemical parameters of the mine's 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 functions of measuring, recording and archiving, informing, warning and switching off the electric current. Due to the further, deeper understanding of the phenomenon of methane emission into roadways, 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 its use to improve work safety in mining [22, 23, 24].

In the paper [24], a set of model parameters for one-day forecasts of methane concentration at the outlet of the roadway of the discharge air exhausted from a longwall was developed. The research on the application of these models to forecast the average methane concentration at the outlets of the longwall ventilation roadways confirmed their satisfactory accuracy [25, 26]. This article presents an attempt of the use of these models to forecast the average and maximum concentration of methane in the roadway of the discharge air from a longwall, where the methane concentration sensor is placed, up to 10 m in front of the wall face and at the outlet of the roadway. The air flow in these places is almost the same, however, the air-methane mixture up to 10 m in front of the wall is much less homogeneous and more variable with time than at the outlet of the roadway.

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

RESEARCH METHODOLOGY

Data on methane concentration are archival and arise from automatic measurements of methane concentration in one of the walls of Jastrzębska Spółka Węglowa SA.

With the methane concentration measurement system software, the measurement data is converted into a text form and output outside the measurement system in the following form:

```
------------------------------------------------------------------------------------------
|      Start Time          | Measurement ‖ Measure time |        Statuses
------------------------------------------------- ----------------------------------------
| 2.03.2020 15:05:20    |   1.0%CH4    |     0:00:01    |                             |
| 2.03.2020 15:05:01    |   1.2%CH4    |     0:00:19    |                             |
| 2.03.2020 15:04:31    |   1.1%CH4    |     0:00:30    |                             |
| 2.03.2020 15:04:19    |   1.3%CH4    |     0:00:12    |                             |
| 2.03.2020 15:04:12    |   1.2%CH4    |     0:00:07    |                             |
```

In the first column of the table above (Start Time), the measurement date and the start time of the methane concentration measurement with its value given in the second column called ‘Measurement’ were recorded. The measurement concentration value provided 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 ‘Measure time’ defines the time when the methane concentration occurs with the value given in the previous column with an accuracy of 1 second. For example, the last line says that on 02/03/2020 from 3:04:12 at the location of the sensor there was a methane concentration of 1.2% for 7 seconds. Then the methane concentration value changed. The new concentration value is entered in the line above. It is 1.3%. This concentration lasted from 15:04:19 for 12 seconds. Further changes in the value of methane concentration are noted above.

In the ‘Statuses’ column, there are notes regarding extraordinary states, e.g., monitoring the accuracy of measurements, exceeding the set concentration threshold, etc. On the basis of the data prepared in this manner, using the PROGMET program developed at the Silesian University of Technology, the average, minimum and maximum values of methane concentration are calculated on a given day, with the day being counted from a given hour, not from 00:00:00. In the data presented in the article, the day was calculated from 06:00:00 to 06:00:00 of the following day. In addition to the above-mentioned data, the duration of individual methane concentration values is counted from 0.0%, every 0.1%, to 2.0%, while the duration of the concentration greater than 2.0% also includes the concentration duration of 2.0%.

The program also counts the number of changes in concentration on a given day.

With input data prepared in this manner, the forecast values of methane concentration are calculated using the models presented herein [24].

CHARACTERISTICS OF MEASUREMENT DATA

The measurement data covers a period of 195 days, with 194 one-day forecasts, as the one-day forecasts use the measurement values of the previous day.

Figure 1 shows the evolution of average methane concentrations in a given day, calculated on the basis of the data collected from a sensor placed in the ventilation roadway up to 10 m in front of the wall face and a sensor placed 10-15 m in front of the outlet of this roadway.

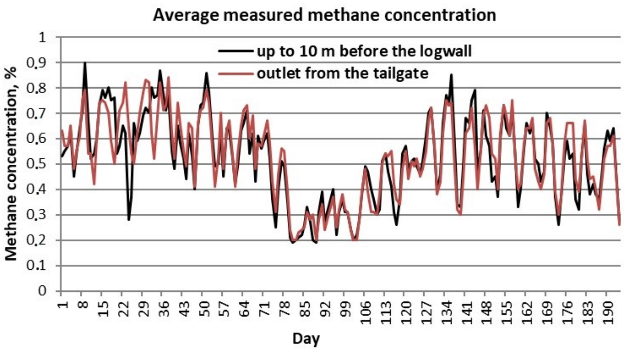

Fig. 1 The average measurement concentration of methane at the sensors' locations in the ventilation roadway

The figure shows a high compatibility of both graphs, although there are also fragments of graphs quite distant from each other. The characteristic parameters of the average methane concentrations detected by sensors in the places mentioned are presented in Table 1.

Table 1
Statistical parameters of average methane concentrations found in the ventilation roadway at a distance of 10 m in front of the longwall and at the outlet of the roadway, calculated for the entire observation period

Parameter	Up to 10 m in front of the longwall	The outlet of the tailgate
mean	0.52	0.53
median	0.53	0.54
percentile 0.9	0.74	0.73
minimum	0.19	0.20
maximum	0.90	0.84
standard deviation	0.17	0.16
coefficient of variation, %	31.87	30.36
range	0.71	0.64
total	100.83	102.28

The mean value and median at the distance of up to 10 m in front of the longwall are only 0.01% lower than the same parameters at the outlet of the roadway. The 0.9 percentile value, minimum and maximum at a distance of up to 10 m in front of the longwall implies that the fluctuations in methane concentration at the outlet from the area are smaller than at a distance of up to 10 m in front of the longwall. The values of the coefficient of variation and the range of fluctuations in the average methane concentration confirm this observation. According to the average values, also the sum of the average concentrations on the individual days of observation at the outlet of roadway is higher than at a distance of up to 10 m in front of the wall. However, the differences in the statistical parameters characterizing both time sequences are small.

In order to assess the usefulness of the use of prognostic formulas developed for the average methane concentration at the outlet area, to forecast the methane concentration up to 10 m in front of the wall, concentration forecasts were carried out in both places and their absolute and relative errors were calculated (Table 2).

Table 2
Statistical parameters of mean methane concentrations found and forecasted at the outlet of the ventilation roadway

Parameter	The outlet of the tailgate – measurement	The outlet of the tailgate – forecast	Differences
mean	0.53	0.54	0.01
median	0.54	0.55	0.01
percentile 0.9	0.73	0.74	0.01
minimum	0.20	0.21	0.01
maximum	0.84	0.84	0.00
standard deviation	0.16	0.15	-0.01
coefficient of variation, %	30.36	27.63	-2.73
range	0.64	0.64	0
total	102.28	105.55	3.27

Figures 2 and 3 show graphs of the mean and forecast concentrations measurements in both places.

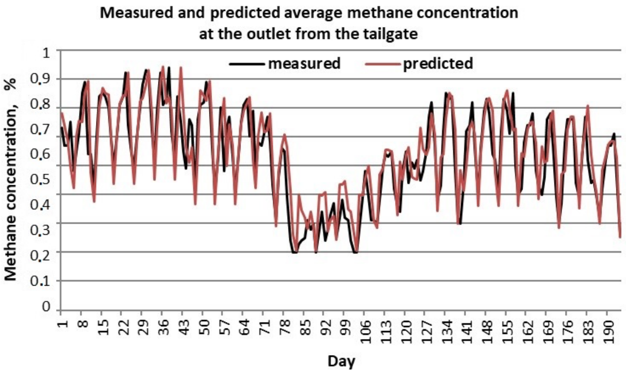

Fig. 2 Mean and forecast methane concentration measurements at the outlet of the tailgate

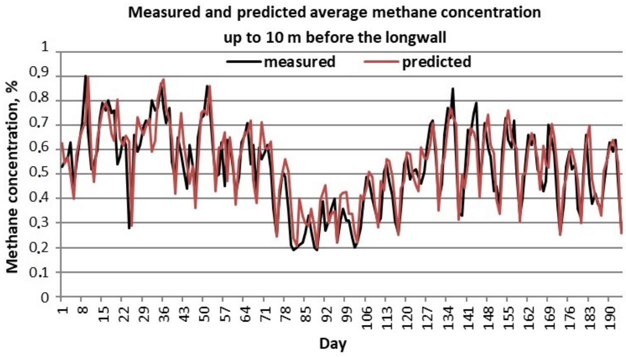

Fig. 3 Measurement average and forecast methane concentration in the over-the-wall sidewalk at a distance of up to 10 m in front of the wall

The average value of the methane concentration, calculated on the basis of measurements made over 194 days, is 0.53% CH_4, while the one calculated on the basis of forecasts is 0.54% CH_4, i.e. it is only 0.01 higher. Such differences also exist between medians, 0.9 percentiles, and minima. Zero differences occur between the maximum values. The coefficient of variation calculated for the forecasts is 2.73% lower than that calculated for the measured values. Therefore, given the entire observation period, the values of the prognostic parameters do not differ much, while the forecast is slightly overestimated. The sum of the forecast values is 3.27 higher than the sum of the measured values.

While analysing the forecast errors, it was observed that the average error of the methane concentration forecast for the entire period is 0.06% CH_4 , and the values of this error ranges between 0.00 and 0.25% CH_4. The sum of the absolute errors is 12.07% CH_4.

The maximum relative error is 73.23%, the minimum is 0.16%, and the average is 13.6%. The median of the relative error is 9.41%. The sum of the relative errors is 2.639%.

Thus, it can be concluded that the conducted forecasts of the average concentration value well approximate their measurement values.

In the further part, it was verified whether the values of errors in the forecasts of methane concentration at a distance of up to 10 m in front of the wall are small enough to be able to say that the forecasts are of significant importance in the mining practice (Table 3).

The average value of the methane concentration calculated on the basis of measurements made on 194 days, is 0.52% CH_4, while the value calculated on the basis of the forecasts is 0.54% CH_4, i.e. higher by 0.02%. The difference between the medians is 0.03% of CH_4, the percentiles of 0.9 are -0.01%, so it is not much underestimated in relation to the measurement. The minimum forecasted value of methane concentration is 0.01% higher than the measurement value, whereas the maximum values do not differ. The standard deviation of the forecasts is lower than the standard deviation of the measurements by 0.02, while the coefficient of variation of the forecasts is lower than that calculated for the measurements by 3.63%.

Table 3

Statistical parameters of mean methane concentrations found and forecasted in the ventilation sidewalk at a distance of up to 10 m in front of the wall

Parameter	Up to 10 m in front of the wall – measurement	Up to 10 m ahead of the wall – forecast	Differences
mean	0.52	0.54	0.02
median	0.53	0.56	0.03
percentile 0.9	0.74	0.73	-0.01
minimum	0.19	0.20	0.01
maximum	0.90	0.90	0.00
standard deviation	0.17	0.15	-0.02
coefficient of variation, %	31.87	28.24	-3.63
range	0.71	0.70	-0.01
total	100.83	104.65	3.82

The forecasts have a slightly narrower range of variation in relation to the measurements and amounts to 0.7%, i.e. is smaller than the range of measurement variation by 0.01%.

Therefore, taking into account the entire observation period, the values of the prognostic parameters do not differ much, while the forecast is slightly overestimated. The sum of the forecasted values is 3.82 higher than the sum of the measured values, so it is only 0.55 more than the forecast calculated at the outlet from the roadway.

When analysing the forecast errors, it was observed that the average error of the forecast of methane concentration for the entire period is 0.07% CH_4, and the values of this error range between 0.00 and 0.35% CH_4. The sum of absolute errors is 13.87% CH_4, which is 1.8% CH_4 greater than the sum of errors at the outlet of the roadway.

The maximum relative error is 125%, the minimum error is 0.10%, and the average error is 15.69%, which is 2.09% higher than at the outlet of the roadway. The median of the relative error is 11.39%, which is 1.98% higher than the relative error at the outlet of the roadway. The sum of the relative errors is 3.044%, which is 405% greater than the sum of these errors at the outlet of the roadway.

The values and numbers of absolute errors of both forecasts are shown in Figure 4.

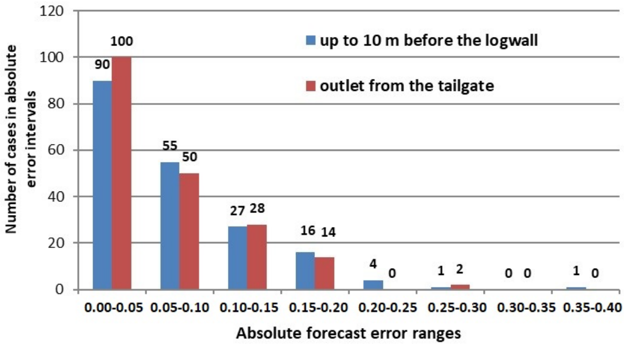

***Fig. 4** Comparison of the number of errors in absolute forecasts of methane concentration*

The number of absolute errors in the range from 0.00 to 0.05% of the methane concentration is close to the half of the observation period. In the case of the forecast at the outlet of roadway, the number of absolute errors in the range of 0.00-0.05% CH_4 is 100, which is 51.5% of all errors, and in the case of forecast at a distance of up to 10 m in front of the wall – 90, which is 46.4% of all errors.

In the range from 0.00-0.10% CH_4, the number of errors is 150 (77.3% of all errors) at the outlet of the roadway and 145 errors (74.7% of all errors) within 10 m in front of the longwall.

In the range of 0.00-0.20% CH_4, the number of errors is 192 (99.0% of all errors) at the outlet of the roadway and 188 errors (96.9% of all errors) within 10 m in front of the longwall.

SUMMARY

It is commonly believed that the longwall methane-bearing capacity in a hard coal mine, understood as the total volume flow of methane emitted into the ventilation air in the longwall area and into the methane drainage system, is a function of the daily extraction from the longwall. A significant number of specialists in the field of methane hazard assume that methane-bearing capacity is a linear function of extraction on a given day, others believe that it is proportional to the element of extraction, and others that the methane-bearing capacity is primarily influenced by the daily longwall progress or the volume of extraction and daily progress.

This article presents an attempt to use models of one-day forecasts of methane concentration to forecast the average methane concentration in the roadway of the discharge air exhausted from the longwall, where the methane concentration sensor is placed, at a distance of up to 10 m away from the wall face and at the outlet of the roadway. The comparison of statistical parameters concerning the forecasts of methane concentration at the outlet of the roadway and at a distance of up to 10 m from the longwall shows that the accuracy of forecasts of average methane concentrations in both places are similar, whereby the forecast of methane concentration in the roadway at a distance of 10 m from the longwall is encumbered with a greater error.

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