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COAL SEAM METHANE PRESSURE AS A PARAMETER DETERMINING THE LEVEL OF THE OUTBURST RISK – LABORATORY AND IN SITU RESEARCH

CIŚNIENIE ZŁOŻOWE JAKO PARAMETR OKREŚLAJĄCY STAN ZAGROŻENIA WYRZUTAMI METANU I SKAŁ – BADANIA LABORATORYJNE I KOPALNIANE

Scarcity of research focusing on the evaluation of the coal seam methane pressure as a parameter determining the outburst risk makes it difficult to assess the value for which the level of this risk increases considerably. It is obvious that, apart from the gas factor, the evaluation of the threat should also take into account the strength factor. The research presented in this paper attempted at estimating the level of the outburst risk on the basis of the coal seam methane pressure value and firmness of coal. In this work, the author seeks to present both the relevant laboratory research and the measurements carried out in mines.

Keywords: Coal seam gas pressure, methane, outburst, firmness

Z powodu niewielkiej ilości badań skupiających się na ocenie ciśnienia gazu jako parametru oceny zagrożenia wyrzutowego, trudno także wskazać przy jakiej wartości tego parametru następuje znaczny wzrost stanu zagrożenia. Oczywistym jest, że ocena stanu zagrożenia, prócz czynnika gazowego powinna uwzględniać także czynnik wytrzymałościowy. W badaniach przedstawionych w niniejszej pracy podjęta została próba oceny stanu zagrożenia wyrzutowego w oparciu o wartość ciśnienia metanu oraz zwięzłość węgla. Praca stanowi próbę kompilacji badań laboratoryjnych i pomiarów kopalnianych.

Słowa kluczowe: Ciśnienie złożowe gazu, metan, wyrzut metanu i skał, zwięzłość

1. Introduction

The notion of the coal seam methane pressure is most commonly defined as the pressure of gas present in pores and cracks in coal. It can be measured by means of a direct method (Lama & Bodziony, 1998; Ostrowski & Ülker, 2007), i.e. under in situ conditions, or by means of indirect

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methods (Dutka et al.,, 2009). Direct measurements were widely used in the mines of the Lower Silesia Coal Basin, where the discussed parameter was of particular importance, as the threat of gas and rock outbursts in the area was considerable (Topolnicki et al., 2004; Wierzbicki & Młynarczuk, 2006). As the experience of researchers from all over the world – including those working in the Lower Silesia Coal Basin (Szewczyk & Kaczkowski, 1992) – indicates, direct measurements of the coal seam methane pressure, carried out under natural conditions, pose certain difficulties. These difficulties, primarily of a technical nature, are the reason why measurements of the discussed parameter – essential as it is for work safety – are so infrequent, both in the Polish and international mining industry.

2. Direct measurements of the porous pressure of methane in coal performed in the Upper Silesia Coal Basin

The measurements of the coal seam methane pressure in strata are carried out by means of probes inserted into boreholes, or casing pipes inserted into long boreholes. Casings in boreholes are typically sealed with cement or glue. In such a case, the measurement is performed for the entire length of the drilled borehole. In the case of probes inserted into research boreholes, sealing is done with elastic stretchers, which allows carrying out measurements and placing probes in boreholes drilled at particular depths within the sidewall. The basic problem concerning measuring the coal seam methane pressure is ensuring proper tightness, which, in turn, guarantees reliable measurement results.

At the Strata Mechanics Research Institute, a measurement probe named IMG-CZ was developed. Its detailed description can be found in (Kudasik et al., 2010). The schematic diagram and the photo of the probe are presented in Figures 1 and 2, respectively.

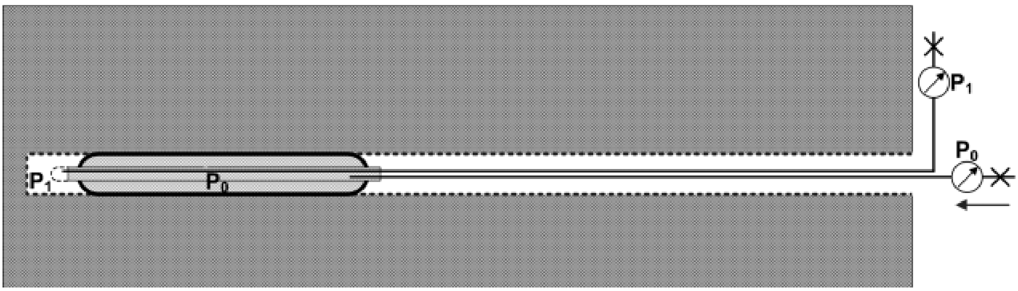

Fig. 1. Schematic diagram of the coal seam methane pressure measurement carried out with the developed measurement probe

Fig. 2. Photo of the measurement probe

The proper construction of the measurement probe (and a considerable length of its sealing part in particular), together with the right selection and construction of rubber sealing elements, made it possible to perform a series of over 50 reliable measurements of the coal seam methane pressure in four mines of the Upper Silesia Coal Basin. The measurement procedure involved placing the probe in a ϕ42 mm research borehole, drilled at the depth of 3-6 m. Subsequently, by means of a hand pump, and via a ϕ4 mm tube made of antistatic polyether-polyurethane, sealing coating was pumped up to the pressure value of ca. 10 bar. During initial tests, it was determined that a proper sealing of the probe in relation to the borehole requires a pressure value which exceeds the pressure being measured by ca. 2 bar. Due to ongoing monitoring of the sealing pressure and the pressure being the object of the measurement, it was possible to increase the value of the sealing pressure, if such a need occurred. After sealing the probe in relation to the borehole, measuring of the coal seam methane pressure began, performed by means of a pressure transformer, via a second pressure tube. Figure 3 depicts the temporal course of recording the pressure in question. The duration of the measurement procedure was not less than 20 minutes. Since the procedure required a break in the drilling activities in the excavation, it was not always possible to record a full course of an increase in the value of the pressure being measured. In such cases, the asymptotic value was estimated on the basis of the extrapolation of the recorded course.

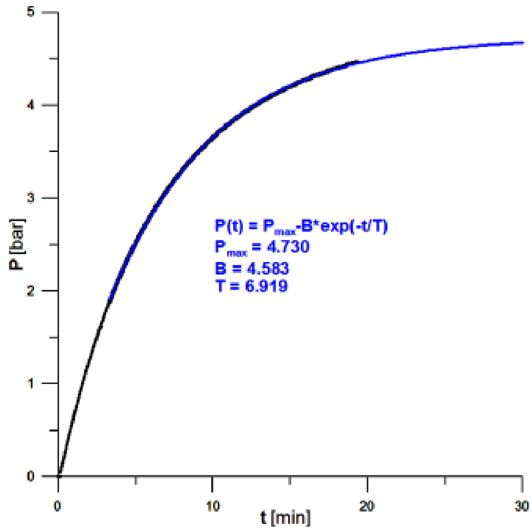

Fig. 3. Measurement of the coal seam pressure – direct result

Apart from measuring the coal seam methane pressure, firmness of the coal was also determined. A comprehensive set of the obtained results can be found in Table 1 below.

TABLE 1

Results of measurements of the coal seam methane pressure and firmness of coal – direct and rated measurements for particular mines

No.	Mine	*f* [-]	*P* [bar]	No.	Mine	*f* [-]	*P* [bar]	Mine	*średnie f* [-]	*średnie P* [bar]
1	mine 1	0,38	1,5	28	mine 2	0,46	3,6	mine 1	0.39	1.24
2	mine 1	0,36	1,6	29	mine 2	0,50	3	mine 2	0.40	3.68
3	mine 1	0,39	0,75	30	mine 2	0,45	4,1	mine 3	1.31	5.38
4	mine 1	0,38	0,09	31	mine 2	0,46	3,6	mine 4	1.03	1.50
5	mine 1	0,38	0,13	32	mine 3	1,66	14,34			
6	mine 1	0,38	0,17	33	mine 3	1,66	7,8			
7	mine 1	0,36	1,91	34	mine 3	0,95	3,4			
8	mine 1	0,36	0,25	35	mine 3	0,99	2,6			
9	mine 1	0,36	0,2	36	mine 3	1,29	3			
10	mine 2	0.34	4,6	37	mine 3	1,20	3,6			
11	mine 2	0,34	2,8	38	mine 3	1,16	3,6			
12	mine 2	0,34	2,4	39	mine 3	1,58	4,73			
13	mine 2	0,34	2	40	mine 4	1,58	2,05			
14	mine 2	0,34	0,3	41	mine 4	1,58	0,15			
15	mine 2	0,34	7,56	42	mine 4	1,58	2,05			
16	mine 2	0,33	4	43	mine 4	1,58	0,15			
17	mine 2	0,33	4,1	44	mine 4	0,65	0,2			
18	mine 2	0,34	4,3	45	mine 4	0,65	1,43			
19	mine 2	0,34	4,6	46	mine 4	0,65	0,1			
20	mine 2	0,34	3,8	47	mine 4	0,65	0,53			
21	mine 2	0,50	4	48	mine 4	0,69	3,32			
22	mine 2	0,44	4,1	49	mine 4	0,69	5,06			
23	mine 2	0,45	3,4	50	mine 1	0,42	3,6			
24	mine 2	0,45	3,5	51	mine 1	0,42	3,0			
25	mine 2	0,44	4,5	52	mine 1	0,42	1,12			
26	mine 2	0,45	3	53	mine 1	0,42	1,8			
27	mine 2	0,45	3,8							

The analysis of the results presented above reveals certain differences between particular mines. Coals in Mine 1 and Mine 2 had relatively low firmness; however, the value of this property was similar in both cases. Still, the value of the coal seam methane pressure recorded in Mine 2 was more than twice as high as in the case of Mine 1. The highest average value of the coal seam methane pressure was recorded in Mine 3, where the most cohesive coal was also found. In Mine 4, the coal was slightly less cohesive, and the average value of the coal seam methane pressure was relatively low. In order to accurately present the level of the outburst risk for particular cases, described by means of the parameters *f* and *P*, relevant laboratory research was carried out.

3. Laboratory research

The laboratory research involved inducing microoutbursts, for different values of coal firmness and the methane saturation pressure. The research was designed in such a way as to make it possible to control the intensity of the outburst induction. The main objective of such research was to find the minimal value of the intensity of the outburst induction (outburst susceptibility), for which this induction would result in an effective outburst. Thus defined outburst susceptibility can be treated as a certain parameter for assessing the level of the outburst risk for particular mining conditions – in this case, represented by the parameters f, P.

As a research material, a properly prepared coal briquette was selected. Such a decision stems from an existing possibility of producing repetitive briquette formations with controlled parameters. The briquettes were tested with respect to their mechanical properties as represented by their firmness. For various briquette porosities ε, corresponding firmness values f were established, in accordance with the procedure specified in the norm (PN-EN 1926). The result is the relation presented in Fig. 4.

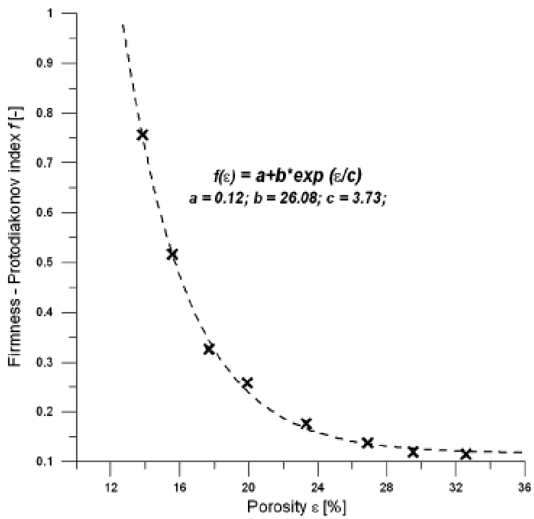

Fig. 4. The f-ε relation for examined briquettes

The basic research was performed with the equipment described below. The equipment was comprised of a thick-walled tube, inside which a briquette of a known porosity was formed. Subsequently, the tube with the briquette was hermetically sealed, which made it possible to pump out the briquette, as well as saturate it with methane under a given pressure. In empty spaces behind and in front of the briquette, pressure transformers, integrated with the system of the data acqusition, were placed. The prepared briquette of a known porosity (and, what follows, of a known firmness (Skoczylas, 2009)) was pumped to vacuum of below 1 mbar, for 24 hours. The coal material was then saturated with methane under a given pressure for 48 hours. The next stage of the experiment was inducing a microoutburst, performed via sudden lowering of the pressure in the chamber in front of the briquette. This was done by hammering out a pivot supporting the lid hermetizing the measuring system. The energy of the gas kept pushing out the lid, and the pressure of the methane in front of the briquette was falling dramatically. The rate of the pressure drop was regulated due to the application of the system of replaceable outflow suppressors (Skoczylas, 2010). Thus, in every measurement cycle, it was possible to carry out a series of experimental outburst inductions for the discussed values f and P, with rising induction intensity. It was assumed that the result of the measurement for the set of points f, P was the lowest value of the time constant of the pressure drop in the chamber in front of the briquette, recorded with a manometer, and essential for effective initiation of an outburst (Fig. 5). The measurement procedure was subsequently repeated for the grid points $f + \Delta f$, $P + \Delta P$, within the firmness range of 0.1-1 and with the interval of 0.1, and within the saturation pressure range of 1.31-31.7 bar and a logarithmically changing interval. As a result, the minimal time constants (expressed in milliseconds) of the methane pressure drop occurring in the chamber in front of the briquette were obtained, allowing an effective initiation of an outburst under laboratory conditions. For the suppressors of the gas outflow combined into the measuring system, the time constants of the pressure drop occurring in the chamber in front of the briquette were between several and 150 milliseconds. These values determine a certain "outburst susceptibility" for particular firmness and saturation pressures. This susceptibility may, in turn, be treated as a specific factor in evaluating the level of the outburst risk. Table 2 presents the direct results of the measurements.

TABLE 2

Minimal time constants of the outburst induction rate, necessary for effective outburst initiation under laboratory conditions

f []	P [bar] 1,4	2,2	3,4	5,3	8,3	13,0	16,2	20,3	31,7
1,0	0	0	0	0	6	10	20	28	120
0,8	0	0	0	0	20	23	25	70	154
0,7	0	0	0	0	20	24	30	111	200
0,6	0	0	0	0	20	24	40	120	200
0,5	0	0	0	5	22	28	75	126	200
0,4	0	0	0	6	25	118	145	200	200
0,3	0	0	0	15	59	141	200	200	200
0,2	0	0	18	61	104	162	200	200	200
0,1	60	200	200	200	200	200	200	200	200

Fig. 5. Briquette destroyed as a result of an outburst induced under laboratory conditions

Whenever it was impossible to effectively induce an outburst for a given set of parameters f, P – although the outflow of the gas from the space in front of the briquette was not suppressed (and the intensity of the induction was maximal) – it was assumed that the outburst risk under such conditions is minimal (the adopted time constant was 0 ms). However, if, for a given set of parameters f, P, an effective outburst took place at the maximal suppression of the outflow of the gas from the chamber in front of the briquette, it was assumed – for the successive pairs of points where the value of the parameter *f* was the same, but the value of the parameter *P* was higher – that the time constant is 200 ms, and the outburst risk under such conditions is the highest.

The obtained minimal time constants of the pressure drop occurring in the chamber in front of the briquette, essential for an effective initiation of an outburst, provide information on the degree of the intensity of outburst induction needed to initiate this outburst effectively under particular mechanical-gas conditions, represented by the set of parameters *f*, *P*. The Author, having normalized these values to 100, treats them as a certain factor in determining the level of the outburst risk.

Fig. 6 presents the obtained results in the form of a relief chart. An increase in the level of the outburst risk (corresponding to an increase in the intensity of outburst induction, necessary for an effective outburst initiation) is illustrated by tonal contrasts from green (minimal threat level) through yellow (average threat level) to red (maximal threat level). The obtained chart depicts the outburst risk as a function of firmness *f* and the seam pressure *P*.

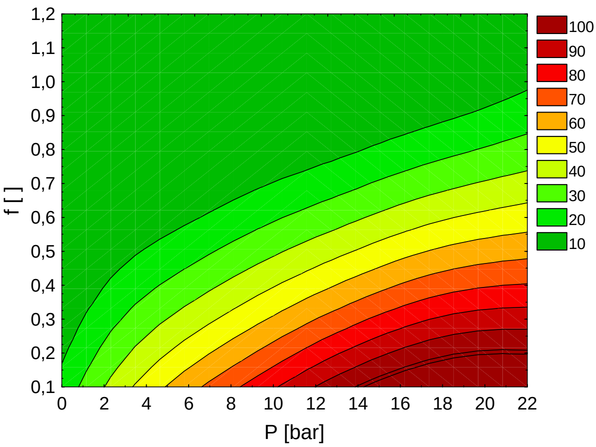

Fig. 6. The outburst risk as a function of the saturation pressure *P* and firmness *f*

4. A critical evaluation of the in situ and laboratory research

Laboratory research is often encumbered with numerous assumptions and simplifications, and it does not fully demonstrate the complexity of a given phenomenon. However, such research is equally often a basic source of our knowledge, and the information that it provides – especially that concerning certain observable trends and tendencies – can be confirmed in practice.

The Author attempted to estimate the level of the outburst risk on the basis of the measured coal seam methane pressure and firmness of coal. The values *f*, *P* were plotted within a outburst risk graph (Fig. 7). Points with particular numbers correspond with measurement values presented in Table 1. Measurement points with firmness values exceeding 1.2 were marked on the upper brink of the chart.

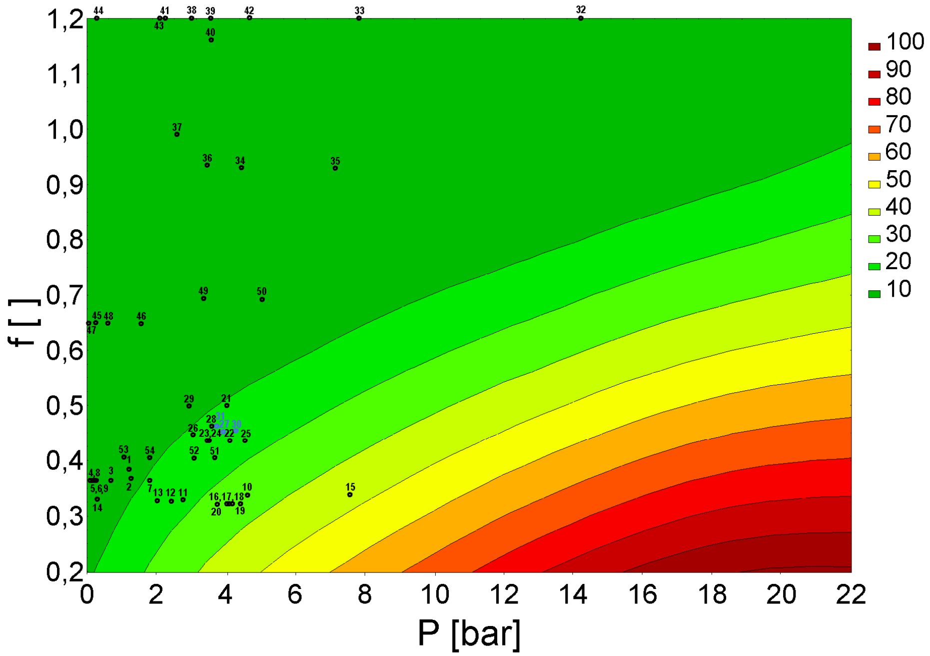

Fig. 7. In situ measurements and laboratory outburst risk

The analysis of the chart with the measurement points plotted on it yields the following conclusions:

- the highest recorded level of the outburst risk (measurement point no. 15) was 50 percent (by laboratory tests) and corresponded with the following values: f = 0.34 and P = 7.53 bar,
- the value of the highest recorded seam pressure was P = 14.34 bar (measurement point no. 32) – in spite of such a high pressure value, the laboratory research indicates the existence of a minimal threat of an outburst, which was due to a very high firmness value f = 1.66,
- the most radical increase in the level of the outburst risk, together with an increase in the saturation pressure, occurs for firmness values of less than 0.6,
- for the firmness values of less than or approximating 0.3, the level of the outburst risk exceeds 50 percent already when the value of the seam pressure is ca. 6 bar,
- high firmness of coal ensures safety, regardless of high values of the coal seam methane pressure.

5. Summary

The coal seam methane pressure is a parameter relatively difficult to determine. Developing proper equipment and measurement methods makes it possible to determine its value in a repetitve manner. With all certainty, it can be stated that the value of the real coal seam methane pressure is not lower than the measured value. Although the occurrence of gas in rocks, under considerable pressure, is a factor widely regarded as crucial in the assessment of the level of the outburst risk, it is difficult to find sources that would allow determining the pressure values that are typical, as well as those that indicate the heightened level of the outburst risk.

The Author undertook to carry out laboratory research exploring the impact of the saturation pressure upon the level of the outburst risk. The research takes account of the gas factor, i.e. the saturation pressure of the sample, and the mechanical factor, i.e. firmness. As a result of performing a series of measurements, differing with respect to the intensity of the induction of outbursts, as well as the parameters f, P, the outburst risk was determined. Particular isolines of the risk level correspond with measurement points f, P, for which the intensities of induction resulting in an effective outburst were identical.

Further, the Author attempted to compare the results of the laboratory tests with in situ measurements. The potentially most dangerous conditions of the parameters f, P were established. Also, it was proved that a radical increase in the outburst risk occurs when the firmness of coal is low. For the high values of firmness, the level of the outburst risk remains low, in spite of the fact that the recorded pressure values were relatively high (> 10 bar).

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