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Abstract

The methane hazard is one of the natural hazards occurring in hard coal mining. The content of natural methane in hard coal seams, the so-called methane-bearing capacity, is one of the key parameters that allow for proper assessment of the methane hazard and the state of the threat of gas and rock outbursts. For safety purposes, there is a constant need to improve the methods for the determination of this parameter. In the conditions of Polish mining, the method used for methane-bearing capacity determination is the direct drill cuttings method. This paper contains a comparative study presenting three different methods of methane-bearing capacity determination. Tests were conducted using two direct methods (the drill cuttings method and the United States Bureau of Mines (USBM) method), and the indirect method based on the desorption intensity index. On the basis of the obtained test results, it was found that the results obtained with the USBM method were slightly higher than those obtained with the direct drill cuttings method. Gas losses, an important element affecting the final value of the assay, were also analysed. This comparative study will evaluate the validity and applicability of the above methods under specific conditions in hard coal mining.

Keywords

hard coal, methane hazard, methane-bearing capacity, mining

RESEARCH ARTICLE

Analysis of the Application of Methane-Bearing Capacity Test Methods in the Conditions of Polish Mining

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Abstract

The methane hazard is one of the natural hazards occurring in hard coal mining. The content of natural methane in hard coal seams, the so-called methane-bearing capacity, is one of the key parameters that allow for proper assessment of the methane hazard and the state of the threat of gas and rock outbursts. For safety purposes, there is a constant need to improve the methods for the determination of this parameter. In the conditions of Polish mining, the method used for methane-bearing capacity determination is the direct drill cuttings method. This paper contains a comparative study presenting three different methods of methane-bearing capacity determination. Tests were conducted using two direct methods (the drill cuttings method and the United States Bureau of Mines (USBM) method), and the indirect method based on the desorption intensity index. On the basis of the obtained test results, it was found that the results obtained with the USBM method were slightly higher than those obtained with the direct drill cuttings method. Gas losses, an important element affecting the final value of the assay, were also analysed. This comparative study will evaluate the validity and applicability of the above methods under specific conditions in hard coal mining.

Keywords: hard coal, methane hazard, methane-bearing capacity, mining

1. Introduction

The methane hazard is one of the most dangerous natural hazards in hard coal mining [1,2,3,4]. The exploitation of coal at increasing depths contributes to increased natural hazards, particularly rockburst and methane hazards [5]. In hard coal deposits, methane occurs in two basic forms: sorbed methane, which is physicochemically bound to a coal substance, and free methane, which occurs in pores and fissures in waste rock and coal [6]. Methane saturation in hard coal seams, i.e. their methane-bearing capacity in mining areas of hard coal mines, determines the level of a methane hazard occurring both during mining operations in methane seams and after their termination [7]. Hard coal exploitation is connected with the release of methane and other gases into the longwall environment, ventilation air, and goafs, which results in the possibility of a potential methane hazard as well as gas and rock outbursts [8,9,10,11,12].

Methane-bearing capacity is defined as a measure of the natural methane content of coal per mass unit (t) of dry, ash-free coal (daf) determined in units of m^3CH_4/t_{daf} [13]. This is a very important parameter for the estimation of methane resources in hard coal seams and the description of the volume and possibility of its release. It is used, among others, in absolute methane content forecasts, which enable an assessment of the methane hazard state as well as a determination of appropriate prophylaxis and methods of methane hazard controlling. The amounts of methane released, obtained as a result of the forecasts, allow for the selection of appropriate ventilation and methane drainage systems and the determination of the maximum amount of its extraction as a result of the conducted mining works [14]. Literature data on methane content studies show that methods used to determine methane-bearing capacity are used both in the mining industry to predict and control gas emission levels in underground coal mines and in the gas industry to calculate existing gas reserves in coal seams [15,16].

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In the conditions of the Polish mining industry, according to the Regulation of the Minister of Environment of 29th January 2013 on natural hazards in mining plants [17], the results of methane hazard research are the basis for assigning a coal seam or its part to a relevant methane hazard category. The Regulation of the Minister of Energy of 23rd November 2016 on detailed requirements for the operation of underground mining plants [18] requires that methane-bearing capacity tests be carried out in corridor excavations in coal seams thicker than 0.4 m, at intervals of no more than 200 m in the plane of the seam and additionally at a distance of no more than 25 m from identified faults causing a break in the continuity of the coal seam or other geological disturbances that may affect the increase in the methane-bearing capacity of the coal seam in places specified by the supervisor of the mining plant operation. According to the above-mentioned Regulation of the Minister of Energy, the basic method for determining the natural methane content in coal (methane-bearing capacity) is the direct method performed by an appraiser. There are differences in the methods adopted by the appraisers, the most important of which is how to determine the gas losses that occur during the sampling for testing. Currently, the method used in the Polish mining industry to determine methane-bearing capacity is the direct drill cuttings method for the determination of methane-bearing capacity in hard coal seams, also called the single-phase vacuum degassing method. The tests are carried out per the Regulation of the Minister of Energy of 23rd November 2016 [18] on detailed requirements for the operation of underground mining plants and the requirements of the PN-G-44200: 2013-10 standard [19].

In the world coal mining industry, there are many methods of determining methane-bearing capacity. They are based on the use of empirical relations between gas content and gas properties of a coal bed, the use of isotherms of methane sorption or hydrostatic pressure as well as other direct and indirect methods [16,20,21,22,23,24,25,26,27]. Research is continuously conducted to determine as precisely as possible the methane-bearing capacity and to identify the phenomenon of gas losses generated at the stage of taking a sample for analysis. This article presents the results of comparative research carried out for three methods used to determine the methane-bearing capacity in the conditions of the Polish mining industry. Two of them are direct methods: the United States Bureau of Mines (USBM) method and the direct drill cuttings method. One is an indirect method based on the determination of the desorption intensity index Δp. The tests were conducted on hard coal samples taken at the same locations and at the same time so that the results could be reliably compared. Four mines in the Upper Silesian Coal Basin were selected for the study. This work aims to analyse the available methods of methane-bearing capacity testing in the conditions of the Polish mining industry and to indicate the differences in possibilities of applying individual methods. The second aim was to analyse the gas losses and the coefficients compensating for the losses that occur at the stage of taking samples for testing.

2. Materials and methods

2.1. Research material

For the purpose of this paper, four mines from the Upper Silesian Coal Basin (USCB) were selected, from which one coal sample was collected for each of the analysed methods, which gave a total of 12 samples. The samples were taken in the same places, at the same time, from the working longwalls. To maintain the confidentiality of the data on the mines from which the samples were taken, they were named A, B, C, and D. For each mine, four core samples of approx. 20 cm were collected for the United States Bureau of Mines (USBM) method, four drill cutting samples for the single-phase vacuum degassing method, and four drill cutting samples for the desorption intensity index test for indirect determination of methane-bearing capacity. The forms of coal sampling and their intended use for individual tests are summarised in the table (Table 1). To best present the differences in the results of the methane-bearing tests through the three selected methods, such coal seams were selected that show different degrees of methane saturation.

2.2. Determination of methane-bearing capacity by the single phase vacuum degassing – direct method

The basic method for determining the content of methane of natural origin in coal (methane-bearing capacity) in the conditions of Polish mining is the direct method performed by an appraiser, which is defined in the Regulation of the Minister of Energy of 23rd November 2016 on detailed requirements for conducting underground mining plants [18]. Methane-bearing capacity is interpreted as the content of naturally-occurring methane in the depth of a coal seam given in m^3CH_4, converted to a tone (t) of clean coal substance (daf). The method complying with the above regulation is the direct

Table 1. Coal samples collected from the mines of the Upper Silesian Coal Basin for methane-bearing capacity testing using different methods.

No.	Coal mine	Research method	Type of sample	Type of method
1	A	USBM	Core	Direct method
2		Single phase vacuum degassing	Drill cuttings	Direct method
3		Desorbometric method	Drill cuttings	Indirect method
4	B	USBM	Core	Direct method
5		Single phase vacuum degassing	Drill cuttings	Direct method
6		Desorbometric method	Drill cuttings	Indirect method
7	C	USBM	Core	Direct method
8		Single phase vacuum degassing	Drill cuttings	Direct method
9		Desorbometric method	Drill cuttings	Indirect method
10	D	USBM	Core	Direct method
11		Single phase vacuum degassing	Drill cuttings	Direct method
12		Desorbometric method	Drill cuttings	Indirect method

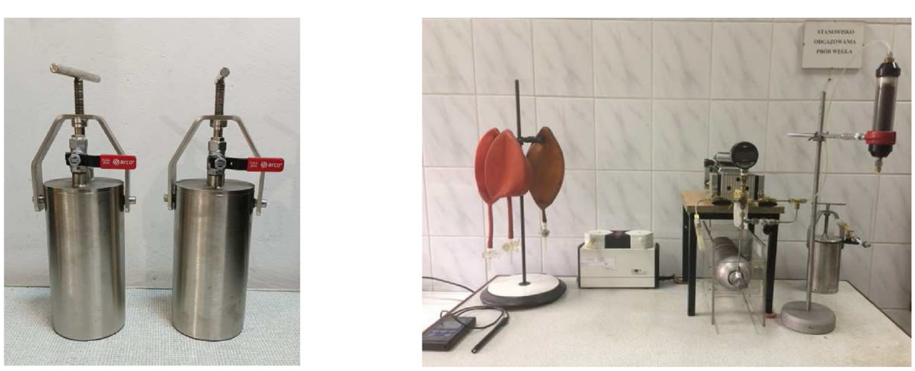
drill cuttings method for the determination of methane-bearing capacity in hard coal seams, also called the single-phase vacuum degassing method. The tests are performed per the above regulation and the requirements of the PN-G-44200: 2013-10 standard [19].

The method consists in collecting coal drill cutting samples into hermetically sealed containers with steel balls (Fig. 1a). In the coal seam or layer, in the face of the excavation drilled at least one day before the samples are taken, two boreholes are made at a distance of at least 1 m from each other. Boreholes are drilled to a depth of 4 m, and collected drill cuttings are sieved on sieves with a mesh size of 1.0 mm and 0.5 mm. The upper fraction is placed in a hermetic container with steel balls (approx. 100 g of sample), and the lower fraction is used to test the indirect methane content by the desorbometric method, which will be described in the next chapter. A drill cuttings sample of coal placed in a hermetic container should be transported to the laboratory, and testing should begin as soon as possible. Two steel containers with coal samples, one from each well, should be submitted for laboratory testing to determine methane-bearing capacity.

The first step in the laboratory testing is to place the container in a special mechanical shaker designed to grind the coal using steel balls placed inside the containers.

After the grinding is completed, the coal samples are subjected to vacuum degassing using the MOD-2 rock sample degassing apparatus (Fig. 1b). The gas obtained from vacuum degassing is subjected to chromatographic analysis to determine the composition of the gases, including methane. The coal sample remaining after degassing is subjected to physicochemical analysis to determine ash content (A), transient moisture (W_{ex}), hygroscopic moisture (W_h), volatile matter content (V^{daf}) and density (d_r) based on prevailing standards [28,29,30]. The results obtained in the individual steps are used for the final calculation of the natural methane content of coal calculated to clean coal substance.

The value obtained as a result of the tests, based on the PN-G-44200: 2013-10 standard [19], is corrected using the loss factor equal to 1.12. The



(a) (b)

Fig. 1. The methane-bearing capacity test stand: (a) hermetic steel containers for coal sampling; (b) MOD-2 test stand for coal samples degassing.

correction of the result is made concerning the potential gas losses occurring at the stage of sampling the coal for testing, which is generated from the moment of starting the drilling until placing the sample in a hermetic container. The Central Mining Institute (Katowice, Poland), as an authorized methane hazard appraiser, uses a coefficient of 1.33. It was determined empirically based on many years of experience in conducting methane-bearing capacity research and observations of coal methane desorption kinetics.

2.3. Determination of methane-bearing capacity by the United States Bureau of Mines (USBM) method – direct method

The United States Bureau of Mines (USBM) method is a direct methane-bearing capacity method used to identify and document coalbed methane deposits. It is based on the free desorption of gas from the coal and makes it possible to determine the volume of the individual gas components, i.e. the content of:

- desorbing gas, which is released in a hermetically closed container and is determined by measuring its volume over time
- residual gas, i.e. the part of the sorbed gas remaining in the coal sample after the completion of the free desorption tests – its volume is determined based on vacuum degassing after the sample has been ground
- lost gas, i.e. the part of the sorbed gas that is released in an uncontrolled manner before the sample is sealed in the hermetic container – its volume is determined by an analytical method

The USBM method makes it possible to follow changes in the gas desorption from coal samples and to determine the dynamically released, desorbable part of the total methane content in coal,

Fig. 2. Hermetic containers for core sampling in the United States Bureau of Mines (USBM) method.

taking into account additional gas losses and its desorption kinetics. The research using this method is based on core samples with a length of 20–30 cm collected in special hermetically sealed containers (Fig. 2). The measurement should be started as soon as possible after the sample is placed in the container and the gas volume reading taken every 15–20 min for the first 24 h. The tests are performed based on the American Society for Testing and Materials (ASTM) standard ASTM D7569/D7569M–10 (2015) [31] and the United States Department of The Interior documentation "The Direct Method of Determining Methane Content of Coalbeds for Ventilation Design" RI 7767 (1973) [32]. In the basic USBM method developed based on Bertard's method [22], the measurement is made by reading the amount of liquid displaced by the desorbing gas in an inverted measuring cylinder. During the measurement of the volume of desorbing gas from the coal core, an analysis of its composition based on gas chromatography is performed. The chromatography tests are performed several times in order to control changes in gas concentration. The volume of desorbing gas is measured until its emission disappears completely. It is assumed that the end of free desorption is the moment when during the next five days, the daily desorption of gas is less than 5 cm^3.

The next step of the test is the measurement of the residual gas volume. For this purpose, a piece of core after free degassing is placed in a 12 cm high hermetically sealed container with steel balls and subjected to grinding for 2 h. Then the volume of the released gas is measured and its composition is analysed by gas chromatography.

Due to the necessity of converting the final result of the methane-bearing capacity determination into a clean coal substance (daf), it is necessary to perform a physicochemical analysis of coal based on the methods described in the standards [28,29,30]. The tests are performed with the use of weighing methods. In addition, as part of the physicochemical analysis, the real density is also determined by helium pycnometry.

The volume of gas lost in the USBM method is determined graphically (Fig. 3) based on the desorption curve determined from the test results obtained. The desorption curve is extrapolated until it intersects with the axis of ordinates. At the intersection of the desorption curve with the ordinate axis, a value is read that corresponds to the volume of gas lost. Based on the volume of desorbing gas, residual, and lost gas and the results of the chromatographic analysis of these gases, taking into account the physicochemical properties, the final

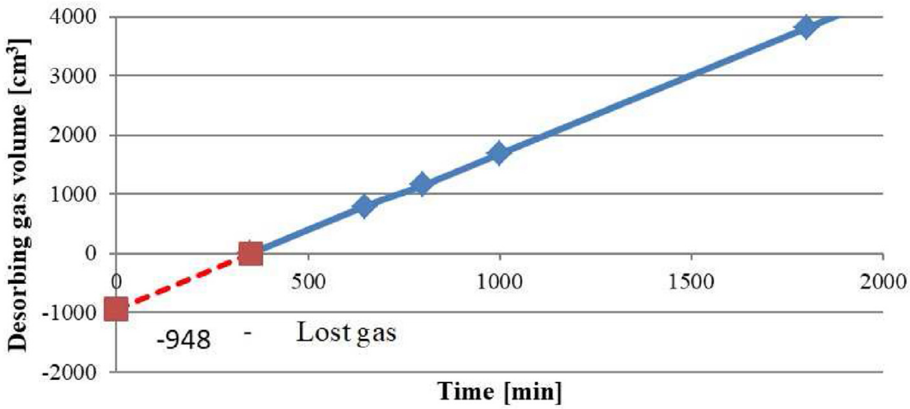


Fig. 3. Determination of the volume of the lost gas in the USBM method.

value of methane content is determined, which takes into account gas losses in a precise and characteristic way for the prevailing conditions and the properties of a given coal sample.

In the Laboratory of Gas Analyses of the Central Mining Institute (Katowice, Poland), the USBM tests are conducted at a constant temperature corresponding to the reservoir temperature using a thermostatic water bath. Unlike the traditional Bartard's method [22] and the one described in the ASTM D7569/D7569M standard [31], a measuring system consisting of a glass gas pipette and a volumetric dropper connected by flexible tubes were used to provide precise readings (Fig. 4). In addition, the entire process is controlled by an electronic system of pressure and temperature sensors.

2.4. Determination of methane-bearing capacity by determining the desorption intensity index — indirect method

Indirect methods for the determination of methane-bearing capacity are based on the use of correlations between gas parameters and the content of methane of natural origin in coal. Their advantage is the time of carrying out the test and the simplicity of implementation, while their results are often burdened with considerable error. The results of methane-bearing capacity tests obtained by indirect methods should not be the basis for determining the coal bed methane-bearing capacity and cannot be the basis for assigning the coal seam to a proper methane hazard category.

The methane-bearing capacity can be determined by an indirect method based on the determination of the desorption intensity index Δp using a DMC-2 liquid manometric desorbometer (Fig. 5) according to the method described in the PN-G-04567:1996 standard [33]. The determination of desorption intensity index is used to determine the degree of coal

Fig. 4. Laboratory of Gas Analyses of the Central Mining Institute — the stand for methane-bearing capacity testing using the United States Bureau Of Mines (USBM) method.

Fig. 5. DMC-2 liquid manometric desorbometer with a dedicated sieve.

seam saturation with gases and to assess the risk of gas and rock outbursts at active mine work faces. The test is carried out by drilling test holes in the coal seam at the face of the excavation being drilled, taking drill cuttings from the appropriate depth of drilling in a time regime of 120 s. For methane-bearing capacity testing, samples are taken from depths of 1.5–2.0 m and 2.5–3 m, and for gas and rock outburst hazard assessment from 2.5 to 3.0 m and 5.5–6.0 m. After sieving the drill cuttings on a special sieve, a 0.5–1.0 mm fraction is obtained, which is placed in a special desorption container. The measurement of desorption intensity is performed during 120–240 s. After this time, the value of the desorption intensity index Δp is read by reading the liquid level in the desorbometer on the scale. The methane-bearing capacity value is obtained indirectly by comparing the received desorption intensity index result with the reference graph described in the PN-G-44200:2013–10 standard [19]. In this way, an approximate value of methane-bearing capacity is obtained.

3. Results and discussion

Based on methane-bearing capacity tests carried out for this article, it was possible to compare three methods used to determine this parameter – two direct methods and one indirect method. This made it possible to present the differences and to identify the method that finds the best application depending on the need and requirements (analysis time, method accuracy). The obtained results are summarized in the table (Table 2) and a bar chart (Fig. 6).

The final result of the methane-bearing capacity determination based on the single-phase vacuum degassing method was obtained using two different gas loss compensation factors. In the former, the final value is presented based on the requirements of the PN-G-44200:2013–10 standard [19] and the results of analyses carried out by other researchers [34,35], in which the final results are given taking into account the loss factor of 1.12, by which the final result of the determination is multiplied. The second method includes the application of the loss factor 1.33 developed empirically by the Central Mining Institute (Katowice, Poland) based on many years of experience in conducting methane-bearing capacity tests and observations of the kinetics of methane desorption from coal. Based on the results obtained, it is concluded that for the applied loss factor of 1.12, the methane-bearing capacity test results were as follows: 7.701; 2.370; 6.396; and 2.217 m^3CH_4/t_{daf},

Table 2. Summary of methane-bearing capacity test results obtained by three different methods.

No.	Coal mine	USBM	Single phase vacuum degassing		Desorbometric method	
		Mo [m^3CH_4/t_{daf}]	*Mo* Loss factor 1.12 [m^3CH_4/t_{daf}]	*Mo* Loss factor 1.33 [m^3CH_4/t_{daf}]	Δp [kPa]	*Mo* [m^3CH_4/t]
1	A	9.293	7.701	9.145	1.100	5.890
2	B	2.959	2.370	2.814	0.240	1.983
3	C	8.159	6.396	7.596	0.850	4.754
4	D	2.650	2.217	2.705	0.340	2.437

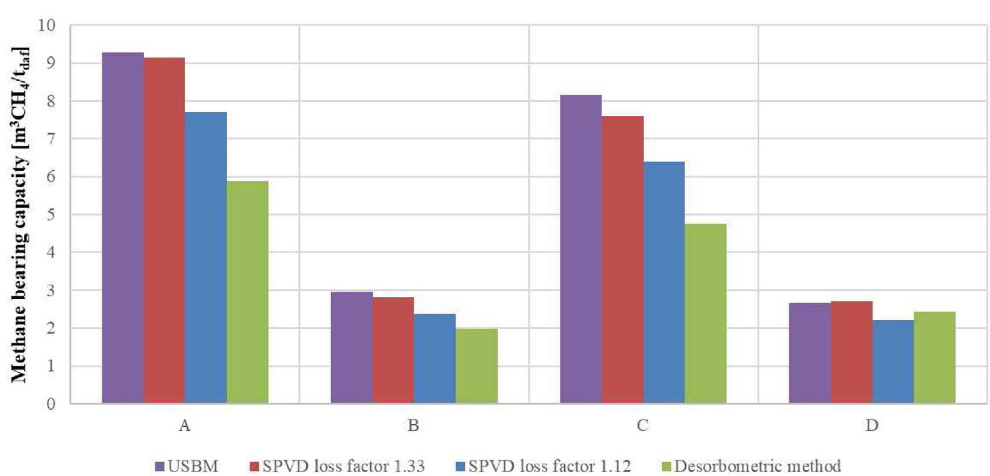


Fig. 6. Comparison of methane-bearing capacity results obtained by three methods: USBM (United States Bureau of Mines), SPVD (Single phase vacuum degassing), Desorbometric method.

while for the applied loss factor 1.33: 9.145; 2.814; 7.596; and 2.705 m^3CH_4/t_{daf}. In comparison, the USBM methane-bearing capacity test results were as follows: 9.293; 2.959; 8.159; and 2.650 m^3CH_4/t_{daf}. The results obtained by the USBM method were higher than those obtained by the single-phase vacuum degassing method for all samples, regardless of the applied loss factor, except the sample from mine D (sample 4). For this sample, the value of methane-bearing capacity obtained by the USBM method was higher than that for which the coefficient of 1.12 was applied, while for the coefficient of 1.33 it was lower, but only by 0.055 m^3CH_4/t_{daf}. The results obtained with the third method – the desorbometric method, were also compared. As a result of these tests, the following values were obtained: 5.890; 1.983; 4.754; and 2.437 m^3CH_4/t_{daf}. The values for this method were the lowest of all the methods used, and for samples from mines A (sample 1) and C (sample 3), the differences were significant. The most similar values were obtained for the sample from mine D (sample 4). This is the only sample for which the methane-bearing capacity value obtained by the desorbometric method was higher than that obtained by the single-phase vacuum degassing method, but only when a loss factor of 1.12 was applied.

Based on the analysis of the test results obtained, it was found that the highest values were received for coal samples taken in the form of a core, and made by the USBM method. These values were similar to those obtained by single-phase vacuum degassing, for which a loss factor of 1.33 was used. Differences in the obtained test results may result, among others, from the sampling method for testing. In the USBM method, core samples are taken, while in the single-phase vacuum degassing method, the drill cuttings are taken. In the case of core samples, the losses generated at the stage of sampling for testing are lower than in the case of drill cuttings. Additionally, in the USBM method, the losses are compensated individually for each coal sample, while in the single-phase vacuum degassing method, a constant factor is used. The differences in the obtained results are presented as a percentage. The methane-bearing capacity result obtained by the USBM method, for which a percentage of 100% was assumed, was set as the baseline and reference result. The percentage differences in the obtained results related to the USBM method are presented in the table (Table 3).

Based on the above data, it can be concluded that for the single-phase vacuum degassing method using a loss factor of 1.12, the methane-bearing capacity determination results were between 16 and 22% lower than those obtained by the USBM method. In the case of the same method, while using the loss factor 1.33, the values were lower by 2–7%, or in one case of mine D (sample 4), this result was higher by 2% compared to the USBM method. As for the indirect desorbometric method, the values were lower between 8 and 42% compared to the USBM method.

Based on the obtained results, it is concluded that a very important factor affecting the final value of methane-bearing capacity is the kinetics of methane desorption from the hard coal structure. During sampling for testing, gas losses are generated from the start of drilling and sample collection until the sample is placed in a hermetic container. The USBM method allows for precise determination of gas components, i.e. the content of desorbing, residual, and lost gas. With the time recorded from the start of drilling to the time the sample is placed in the hermetic container in the USBM method, the gas loss can be precisely determined. In the single-phase vacuum degassing method, a constant loss factor is assumed regardless of how fast the sample releases gas, which is a key element when determining methane-bearing capacity. In addition, the samples for the USBM method are collected in a core form, which to some extent, reduces the losses generated when collecting drill cuttings samples for the single-phase vacuum degassing method. The desorbometric method is only appropriate for indirect, indicative determination of methane-bearing capacity because its values are often underestimated. However, it is the fastest method, as a result is obtained only about 5 min after drilling under the mine conditions. The USBM method, although it seems to be the most precise and the most accurate, also has a disadvantage, which is the

Table 3. Differences in obtained methane-bearing capacity test results expressed as a percentage compared to the reference USBM method.

No.	Coal mine	USBM	Single phase vacuum degassing		Desorbometric method
			Loss factor 1.12	Loss factor 1.33	
1	A	100%	83%	98%	63%
2	B	100%	80%	95%	67%
3	C	100%	78%	93%	58%
4	D	100%	84%	102%	92%

analysis time. As with the single-phase vacuum degassing method, test results can be obtained up to 24 h, while in the USBM method, free core desorption takes from 2 weeks even to over a month.

In the work of Diamond and Schatzel [21], it was determined that direct methods for determining methane-bearing capacity can be divided into rapid crushing methods and extended desorption methods. In the first category, we can include the single-phase vacuum degassing method in which drill cuttings samples are collected and immediately crushed with steel balls in the laboratory. In the second category, i.e. extended desorption methods, we can include the USBM method based on the analysis of free gas desorption from a coal core. It can be stated that the single-phase vacuum degassing method is appropriate for routine control of methane hazards in hard coal mines, while the USBM method is appropriate for assessing the size of methane resources in hard coal seams, the possibility of its extraction, and for modelling the deposit or carrying out verification of methane-bearing capacity determination.

Based on the conducted research, it is stated that a very important aspect of the methane-bearing capacity determination is the gas losses generated at the stage of sampling for testing. It was determined that the USBM method was the most precise in taking into account individual gas losses for each analysed coal sample. The most similar values are obtained for the single-phase vacuum degassing method using a loss compensation factor of 1.33. It has been found that the kinetics of methane sorption has a very important influence on the proper determination of the methane-bearing capacity, which was also reported by other researchers [8,36,37,38,39]. This is important in terms of determining the rate of gas release and generating losses at the sampling stage for testing. The analysis of the methane content determination methods carried out in this article is the basis for further considerations on this issue, especially in terms of the detailed impact of methane sorption kinetics on gas losses.

Based on the conducted analysis, it has been stated that the single phase vacuum degassing method seems to be appropriate for routine control of the methane hazard state in hard coal mines, while the USBM method is appropriate for the assessment of the methane resources amount in hard coal seams and possibilities of its exploitation as well as for the verification of methane-bearing capacity determination for longwalls.

From a scientific point of view, the presented research contributes to better recognition of gas losses at the stage of coal sample collection for methane-bearing capacity testing.

4. Conclusions

This paper presents the results of the methane-bearing capacity test obtained by three different methods. Two of them are direct methods: the single-phase vacuum degassing method and the United States Bureau of Mines method. The research results for the indirect method, i.e. the desorbometric method, are also presented. Based on the analysis, the following conclusions were drawn:

- Direct methods are methods that should be applied for the proper determination of methane content in coal (methane-bearing capacity). They should be applied to determine the state of methane hazard in hard coal mines and may be the basis for classifying a coal seam into a proper methane hazard category.
- Indirect methods for methane-bearing capacity determination are based on using the correlation between gas parameters and methane content of natural origin in coal, which have the advantage of simplicity, however, their results are often burdened with significant error. The results of methane-bearing capacity research obtained with the use of indirect methods should not be the basis for determining the methane-bearing capacity of coal beds and cannot be the basis for defining a coal bed to a proper methane hazard category.
- Direct methods for determining methane-bearing capacity can be divided into rapid crushing methods (single-phase vacuum degassing method) and extended desorption methods (United States Bureau of Mines method). The single-phase vacuum degassing method is appropriate for routine control of the methane hazard state in hard coal mines, whereas the USBM method is appropriate for the assessment of the size of methane resources in hard coal seams, possibilities of its exploitation, and for modelling the deposit or carrying out verification of methane-bearing determination for longwalls.
- The highest methane-bearing capacity determination results were obtained for the United States Bureau of Mines method, which appears to be the most precise and capable of determining individual gas losses for a given coal sample. The average analysis time for this method ranges from 2 weeks to over a month.
- The single-phase vacuum degassing method uses a loss factor of 1.12 determined by other

researchers and specified by the standard, or 1.33 determined by the Central Mining Institute (Katowice, Poland). The use of coefficient 1.33 gives results close to those obtained by the United States Bureau of Mines method.
- The lowest results were obtained for the indirect desorbometric method, for which values were on average 8–42% lower than the United States Bureau of Mines method.
- An important aspect during the determination of methane-bearing capacity is the gas losses generated from the moment of starting the drilling for collecting the sample for testing until the moment of placing the sample in a hermetically sealed container. This rule applies to both drill cuttings and core samples. Therefore, a very important aspect is the analysis of methane sorption kinetics, which is crucial in determining gas losses.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflict of interest

The authors declare no conflict of interest.

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