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Drilling muds for coal deposits

Płuczki do przewiercania pokładów węgla

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ABSTRACT: The instability of coal beds, both in the overburden and in the production zone during drilling, in particular with directional borehole, is well known. One of the main coal attributes is presence of cracks and micro-fractures in it. This linked network of cracks is considered as the main source of many problems related to coal instability. Stresses occurring in such formations exceed the coal compressive strength. During drilling, coal becomes unstable, which can result in borehole wall collapsing, stuck pipe, or even complete loss of the borehole. Using improper drilling muds can cause additional problems. In coal, a poorly selected drilling mud can damage the natural permeability of the near-well zone. Drilling muds penetrating the pores and cracks in the coal can lead to permanent destruction of the near-well zone, partially or completely limiting the supply of methane to the borehole. Muds used for drilling in coal deposits should therefore both stabilize the borehole wall and affect minor damage to the drilled formation. The experience acquired while drilling low-permeability shale rocks generally does not correlate with the practices and guidelines used to drill holes in coal deposits due to the unique physical and mechanical characteristics of coal. One of the ways to improve the stability of coal deposits when using water-based drilling muds is to prevent the penetration of mud filtrate into the rock matrix, which can be achieved by chemical modification of the drilling mud composition or physical sealing of pores and fractures with special materials. The article presents research on the development of a new drilling mud system dedicated to coalbed methane (CBM) drilling.

Key words: drilling mud, coalbed methane (CBM), coal seams, borehole instability, lost circulation.

STRESZCZENIE: Niestabilność pokładów węgla zarówno w nadkładzie, jak i w strefie produktywnej podczas ich rozwiercania, w szczególności otworami kierunkowymi, jest powszechnie znana. Jedną z głównych cech węgla jest występowanie w nim systemu spękań i mikroszczelin. To właśnie tę połączoną sieć spękań uważa się za źródło wielu problemów związanych z niestabilnością węgla. Występujące naprężenia w takich formacjach przewyższają wytrzymałość węgla kamiennego na ściskanie. Podczas realizacji prac wiertniczych węgiel kamienny staje się niestabilny, może dochodzić do obsypywania ścian otworu, przychwycenia przewodu, a niekiedy do całkowitej utraty otworu. Zastosowanie do wiercenia niewłaściwych płuczek wiertniczych może powodować dodatkowe problemy. W skale, jaką jest węgiel kamienny, źle dobrana płuczka wiertnicza może uszkodzić naturalną przepuszczalność strefy przyotworowej. Płuczka, wnikając w pory oraz spękania węgla, może doprowadzić do trwałego zniszczenia strefy przyotworowej, ograniczając częściowo lub całkowicie dopływ metanu do otworu. Płuczka wiertnicza stosowana do przewiercania pokładów węgla powinna zatem zarówno stabilizować otwór podczas fazy wiercenia, jak też wpływać na niewielkie uszkodzenie przewiercanej formacji. Doświadczenia nabyte podczas przewiercania skał łupkowych o niskiej przepuszczalności na ogół nie korelują z praktykami i wytycznymi w zakresie wiercenia otworów w pokładach węgla z uwagi na wyjątkową charakterystykę fizyczno-mechaniczną węgli. Jednym ze sposobów poprawy stabilności utworów węgla przy wykorzystywaniu wodnodyspersyjnych płuczek wiertniczych jest przeciwdziałanie wnikaniu filtratu płuczkowego do matrycy skały, co można osiągnąć poprzez chemiczną modyfikację składu płuczki wiertniczej lub fizyczne uszczelnianie porów i szczelin specjalnymi materiałami. W artykule przedstawiono badania nad opracowaniem nowego systemu płuczki wiertniczej przeznaczonej do rozwiercania złóż metanu zlokalizowanego w pokładach węgla kamiennego.

Słowa kluczowe: płuczka wiertnicza, metan z pokładów węgla, pokłady węgla, niestabilność otworu, zaniki płuczki.

Introduction

Hard coal features high variability of chemical and technological parameters. The hard coal properties to a large extent depend on the conditions, under which this raw material originated. A high temperature and pressure, accompanying diagenetic and metamorphic processes, were most important.

The coal quality is a measure of chemical transformation (referred to also as "diagenesis"). The longer is the coalification, the higher is the quality and vitrinite content of the

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coal. The vitrinite content changes with the coal quality, like a few other physical properties important for the potential of methane existence in coal beds. Porosity is the basic parameter affecting the coal properties. The coal pore structure not only directly determines the gas adsorption and coal desorbability (Chakhmakhchev, 2007; Hadro and Wójcik, 2013; Baltoiu et al., 2016; Robbins et al., 2016; Li et al., 2018), but also impacts the interaction between the rock pores and the drilling fluid. Permeability is the second, not less important parameter and directly related to porosity, which is a decisive factor affecting the possibility to extract methane from the seams. Permeability in coal is a direct function of a grid of cracks and fissures in the coal matrix existence. As a result of drainage and coalification in the organic matter the coal matrix shrinks and breaks and fractures start to originate. Cracks originate in the coal matrix also due to tectonic stresses. This type of formed cracks is referred to as 'tectonic breaks'. Because of their existence the coal permeability increases as well as due to their connection with some cracks originated e.g. as a result of drainage and organic material shrinkage during the coalification. The type of maceral and coal quality are two most important factors, which determine the development of cracks and breaks in coal (Zhang et al., 2010; Zhao et al., 2012; Benguang et al., 2013; Baltoiu et al., 2016; Li et al., 2018).

Substantial amounts of methane exist in hard coal deposits, creating explosion and fire hazards during mining. Properly captured and managed methane can be a valuable energy raw material. Methane existing in coal seams is an almost clean gas and its nature basically differs from conventional gas. Coalbed methane (CBM) forms as gas of biogenic or thermogenic origin. The former results from a bacterial conversion of carbon to CO_2 or acetate, which is next converted by *Archaea* to CH_4. The thermogenic gas originates in the process of coalification, being a process of chemical degassing, during which CH_4 is released. Methane is adsorbed on the coal surface; hence the pore area determines the maximum potential of gas existence in the deposit. From a practical point of view the amount of biogenic origin gas is always smaller than the content of the thermogenic origin gas. The amount of methane from coal seams of biogenic origin rarely exceeds 4 to 6 m^3/t of coal. Instead, the amount of gas that may be obtained from thermogenic origin coals can even exceed 20 m^3/t of coal. Seams of both biogenic and thermogenic origin coal can frequently exist within one deposit. Effective coal permeability decreases with the depth and with acting overburden stresses. Methane can exist as free gas in the network of cracks and fissures or as trapped gas adsorbed in the coal matrix or in the micropores structure (Chakhmakhchev, 2007; Moore, 2012; Baltoiu et al., 2016). Majority of methane resources exist in coal micropores. The main property, differing coal deposits from conventional deposits (i.e. existing in sandstones or carbonates) is the source of hydrocarbons origination. In conventional deposits hydrocarbons originate in source rocks and then migrate to porous rocks, being reservoir rocks for those hydrocarbons. Instead, the coal matrix is both a source and reservoir rock for hydrocarbons.

The extraction of methane deposits from coal seams is now carried out in many countries worldwide, including the USA, Australia, China, India, Indonesia, and Canada.

Poland has significant methane resources in hard coal seams. The greatest documented resources of methane situated in hard coal seams in Poland exist in the Upper-Silesian Coal Basin. The Upper-Silesian Coal Basin (SCB) features diversified and complicated natural conditions of methane existence. Up to now the amounts of methane captured form Carboniferous formations from the SCB area between 1951 and 2005 are estimated at approx. 10 billion m^3. However, the majority of methane production in the SCB originates from the methane drainage of the mined coal deposits. The captured methane constitutes approx. 30% of the methane released from hard coal deposits during mining (Habera, 2016; Jureczka, 2016; Słoczyński and Drozd, 2017).

Issues occurring during coal deposits development

The instability of coal seams during their development, in particular by directional drilling, is widely known, both in the overburden and in the productive zone.

The existence of a system of cracks and micro-fissures is one of main coal features. The connected network of fractures is considered the very source of many problems related to its instability. There are various theories on the fissures in coal origination, like tectonics, proceeding processes of drainage and of organic material shrinkage. Fissures and cracks in coal exist most often perpendicular to each other and perpendicular to the bedrock plane and may be 3–40 µm wide (Clarkson and Bustin, 2011; Baltoiu et al., 2016; Zhang et al., 2016; Li et al., 2017; Zheng et al., 2018). Stresses existing in such formations exceed the hard coal compression strength. Drilling of a certain volume of rock results in the stress concentration close to the borehole walls, which earlier acted on the removed rock. An increased stress concentration causes that the borehole tries to shrink radially. If the effective stress acting on the rock exceeds its compression strength, the borehole walls can be decalibrated resulting in its filling. Numerous cases described in papers are known in practice, that an initially stable borehole due to filtration of the drilling fluid into pores of drilled formations changes into an unstable borehole (Gentzis et al., 2009; Josh et al., 2012; Yan et al., 2014; Baltoiu et al., 2016; Qiong et al., 2016).

Many papers show that the invasion of the drilling mud into naturally existing fractures is one of main issues occurring during coal drilling, which results in increasing the pore pressure of the drilled formations and causes the borehole walls falling. There are suggestions, that maintaining of hydrostatic pressure of the drilling fluid below the calculated pressure of fissure propagation in coal is the key to coal stability management, to avoid increasing the pressure in existing rock cracks and pores. The increasing of the drilling mud density to improve the borehole stability can have disastrous consequences, especially in the case of a naturally fractured formation (Clarkson et al., 2007; Zheng et al., 2016, 2018). To increase stability of drilled coals it is necessary to seal fissures and cracks existing in the coal. It is generally known that the filtration deposit forming on drilled coal rocks does not cause total sealing and the drilling mud continues penetrating to the rock matrix. The relation between such factors as the mud filtration rate, the range of mud filtrate penetration into the rock, coal strength, and the borehole geometry have a decisive importance in the process of boreholes drilling in coal seams (Gentzis, 2009; Moore, 2012; Zhang et al., 2016).

During drilling through highly fractured coals there is a high probability of drilling mud losses. The mud invasion into the network of cracks results in increasing the pore pressure of drilled formation and in depositing drilled coal parts (borings) and mud components (loading materials) in coal cracks and micro-fractures.

A traditional method to improve stability of drilled coal seams consists in increasing the drilling mud density and viscosity as well as the drilling mud pumps yield for more effective uplift of the drillings. There is also a practice of adding the LCM materials to the drilling mud. After a thorough analysis none of the applied practices gives the expected results. The increased drilling mud density results in improved stability of drilled layers only for a short period of time. The loading material, i.e. the calcium carbonate or barite, migrates with the drilling mud to cracks and fissures partly supporting the already open micro-fractures, enabling further drilling mud losses. During a short time the pressure existing in the borehole and the pressure of drilled formations equalise. As a result, the borehole walls can fall (Chakhmakhchev, 2007; Benguang et al., 2013; Baltoiu et al., 2016).

The introduction of LCM materials to drilling muds, preventing their losses, also does not bring the expected results. Hard and stiff particles act as filling materials, leading in this way to increased drilling mud losses. Moreover, such materials migrate deep within breaks and cracks, significantly reducing the coal permeability. Conventional LCMs (e.g. fibres, cellophane, shells, hulls, etc.) are too large to create effective sealing (Gentzis, 2009; Gentzis et al., 2009; Moore, 2012; Baltoiu et al., 2016).

In the case of drilling through highly fractured coal seams it is recommended to limit the borehole drilling speed. When it is controlled it is easier to detect symptoms of borehole instability and to respond quicker before they become a serious issue. At drilling through coals there is no need to apply a high speed of drilling mud outflow from the drill nozzles because of maintained small borehole drilling speed and also due to the lack of coal borings accretion.

Bentonite and potassium-polymer drilling muds are frequently used to drill through coal seams, which quite often are the reason for lost circulation and damage to the natural permeability induced by the hydraulic pressure difference (Lu et al., 2010; Cai et al., 2016; Li et al., 2018). Because of coal low porosity and permeability it was determined that the gas flows to the borehole mainly through natural cracks and fissures. The coal matrix features strong absorbing properties of liquids and gases, because it contains a lot of organic humic particles. Because of that, even a small increase in the coal matrix volume resulting from the swelling of humic substances or existing clayey materials admixtures can cause significant deterioration of permeability.

The performed permeability tests on coal samples showed a negative impact of frequently used bentonite drilling muds and those containing additions of LCM materials. Cases of drilling through coal seams by means of compressed air are also known, at which it is possible to obtain a high drilling progress at small damage to permeability. However, it is not a method recommended in the case of drilling through unstable or loose coal seams (Wang et al., 2015; Wu et al., 2015).

Laboratory studies on development of drilling fluid compositions for coal seams drilling

Two types of drilling mud were suggested to drill through coal seams because of frequent drilling mud losses during coal seams drilling and low formation pressures of coal formations. The first of them is the CBM1 drilling mud, being a kind of potassium-polymer mud, in which composition two types of sealants were applied. 'PAP' sealant was applied to seal bigger cracks and fissures existing in the coal, which under the influence of water creates a kind of elastic sealing in the coal fractures network. This agent was added to the drilling mud at an amount of 0.2%. The second type of the applied agent was so-called aluminium complex, consisting of aluminium compounds and organic humic acids. This agent task consists in sealing small pores existing in the coal and preventing an increase in the pore pressure of drilled through coal formations. The aluminium complex was added to the drilling fluid at an amount of 1 vol%. Table 1 presents the composition and properties of the developed CBM1 drilling mud. The developed drilling mud featured plastic viscosity of 21 mPas, yield point of 14.3 Pa, and filtration of 3.6 cm^3/30 min. (Table 1). In addition, graphite was used as a loading material in the drilling mud composition, which addition improves also lubricating properties of the mud.

Table 1. Composition and properties of the CBM1 drilling mud
Tabela 1. Skład i właściwości płuczki CBM1

Drilling fluid composition [%]		Density [kg/m³]	Viscosity [mPa · s]		Yield point [Pa]	Gel strength [Pa]	Filtration [cm³]	pH
		ρ	η_{pl}	η_s	τ_y	I/II		
Biostat XCD Gelatinised starch PAP KCl Aluminium complex Graphite	0.1 0.3 3.0 0.2 3.0 1.0 3.0	1040	21	36	14.3	2.4/3.3	3.6	10.9

The second type of drilling mud, recommended especially to drill through coal seams featuring low reservoir pressures, is a 'fuzzy-ball' type drilling fluid with reduced density, containing air bubbles as the sealing material. Such muds were already tested in more than 1000 boreholes in China (Zheng et al., 2012, 2018). The composition and properties of such muds are very similar to an aphron mud. Basing partially on the result of studies on an aphron mud developed at the INiG – PIB (Błaż, 2013), studies revising the hitherto composition of the aphron mud were carried out, changing the composition of a foaming agent and of an agent increasing the durability of formed air micro-bubbles in the drilling mud system. Air micro-bubbles in the drilling mud were produced by its mechanical foaming, using properly chosen surfactants with foaming properties.

Table 2 presents the composition and properties of the CBM2 drilling mud. The CBM2 drilling mud at 20°C features a density of 810 kg/m^3, contains 22.1% of air micro-bubbles with half-time exceeding 290 h. The drilling mud's plastic viscosity is 34 mPas, and the yield point – 32.5 Pa. Moreover, the drilling mud features high viscosity values at low shear rates equal to 78000 mPas, a high pH value of 11.1, and filtration equal to 4.8 cm^3/30 min. (Table 2).

Studies on the impact of developed CBM1 and CBM2 drilling muds on coal properties

Pore pressure tests (PPT) on coal samples

One of main issues occurring during coal drilling is the invasion of the drilling mud into naturally existing cracks, resulting in increasing the pore pressure in coals. The reduction of pressure under which the filtrate from the drilling mud penetrates pores in the drilled through rocks is one of more important factors that decide about retaining borehole walls stability. It is considered that an appropriate pore pressure stabilises rocks and maintains integrity of the drilled layers. As a result of drilling mud invasion into cracks and fissures the pore pressure in coals increases and hence the pressure difference, existing between the hydrostatic pressure of the drilling mud and the pressure of the drilled formation, decreases. At significant drops of the pressure difference the stresses existing in the borehole change, resulting in borehole walls falling, and ultimately even in borehole filling.

The studies on the pore pressure transmission were carried out on coal samples from mine B1, featuring porosity of 5.57% and pore permeability of 0.39 mD.

Table 2. Composition and properties of the CBM2 drilling mud
Tabela 2. Skład i właściwości płuczki CBM2

Drilling fluid composition [%]		Density [kg/m³]	Viscosity [mPa · s]		Yield point [Pa]	Gel strength [Pa]	LSRV viscosity at 0.06 s⁻¹ [mPa · s]	Air content in the mud [%]	Filtration [cm³]	pH
		ρ	η_{pl}	η_s	τ_y	I/II				
Biostat Na_2CO_3 biopolymer APV RCH50 KCl Gelatinised starch CMC LV Stabiliser P Blocker M25 Graphite	0.1 0.6 0.7 0.2 0.3 3.0 2.0 0.5 0.6 3.0 1.0	ρ_1 –810	34	68	32.5	12.9/14.3	78000	22.1	4.8	11.1

Figure 1 presents values of coals pore pressure for selected drilling muds. An increase in the pore pressure originates as a result of mud filtrate flow through the core. Instead, the pore pressure is reduced due to sealing the pore surface of the rock by the formed filtration deposit and limitation of the mud filtrate flow through the coal.

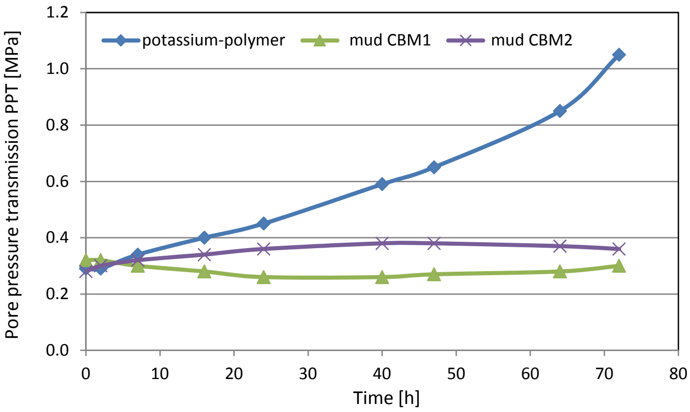

Fig. 1. The values of pore pressure transmission (PPT) of coal during drilling mud flow

Rys. 1. Wartości ciśnienia porowego węgli podczas nasączania ich wytypowanymi płuczkami wiertniczymi

Coal samples were saturated on the deposit side with a 3% KCl solution at a pressure of 0.2 MPa, and on the borehole side with drilling muds at a pressure of 1.8 MPa. Coal cores were saturated during 72 h. Obtained results are presented graphically in Figure 1. As a result of coal saturation with a potassium-polymer mud the pore pressure increases to 0.34 MPa already after 7 h. After 24 h of potassium-polymer mud saturation the pressure went up to 0.45 MPa, and after 40 h – to 0.59 MPa (Fig. 1). The final pore pressure in coal measured after 72 h of test was 1.05 MPa. The obtained results of coal pore pressure increase for the potassium-polymer mud may prove that the deposit formed from the mud does not seal the pore space and because of that during all the test the mud filtrate was penetrating, thereby causing the coal pore pressure growth.

As a result of coal core saturation with the CBM2 drilling mud with a density of 810 kg/m^3 the initial pore pressure was systematically decreasing. After approx. 15 hours the pore pressure went down to 0.28 MPa, and after 40 h of test – to 0.26 MPa. Then the pore pressure started to increase slightly, to reach a value of 0.29 MPa after 72 h (Fig. 1). The CBM1 drilling mud featured slightly better properties of the pore space sealing; its application caused limitation of the pore pressure growth. Initially, as a result of the mud penetration, the pore pressure after 40 h of test increased to 0.38 MPa. In the next hours the pressure stabilised and maintained on a similar level of 0.38 MPa. After 64 hours the pore pressure slightly went down to 0.37 MPa, and after 72 h – to 0.36 MPa. (Fig. 1). The CBM1 drilling mud created effective sealing, which limited the flow of mud filtrate through the coal core, limiting the pore pressure increase.

The carried out tests showed that the developed drilling muds to drill through coal seams, CBM1 and CBM2, effectively seal the coal pore pressure, thereby effectively limiting the mud filtrate flow and the increase in the coal pore pressure.

Determination of sealing properties of developed drilling muds

During drilling through highly fractured coals there is a high probability of drilling mud losses. At threats related to mud losses it is practised to apply materials preventing the lost circulation (LCM). Usually these are materials of various shapes and grain sizes, which are added to the mud in such a way, that they could create a seal in the loss area. Because of uneven arrangement of pores and cracks in the coal matrix, the theoretical calculation of the sealant size for the existing rock pores is usually ineffective. At the same time the shape of cracks and microfissures existing in the coal is very irregular. Therefore the LCM materials limit the issue of mud losses only to some extent. In addition, stiff LCM materials can migrate with the mud to coal cracks and fissures partly supporting the already opened microbreaks, enabling further mud penetration (Baltoiu et al., 2016).

Studies on determination of developed drilling muds sealing properties were carried out on a sand bed with grain sizes from 0.25 to 1.0 mm (Table 3).

The effectiveness of rock pores blocking was determined based on the amount of mud flowing out after 30 minutes under a pressure of 0.7 MPa. The tests on CBM1 filtration through the bed confirmed its sealing properties. In the initial test phase the mud started filtrating into the bed. Then, after approx. 2 minutes, a deposit was formed on the sand bed, which sealed pores existing between sand grains and further mud filtration was limited. After 30 minutes of the test the mud invasion into the bed was 7 cm, while the mud filtration through the bed was reduced to zero (Table 3, Photo 2). Mud CBM2, with a density of 810 kg/m^3 and high values of LSRV viscosity at low shear rates, featured slightly better sealing properties. The mud presented for tests contained approx. 22.1 vol.% of air micro-bubbles with sizes ranging from 10 to 300 µm (approximate sizes of micro-bubbles were determined by means of a microscopic method). The tests of filtration through the bed confirmed a possibility of pores and fissures blocking by air micro-bubbles contained in the mud. The mud invasion into the bed was approx. 2 cm^3 and the filtration was reduced to zero (Table 3, Photo 3). Also tests on the potassium-polymer mud were carried out for comparison, The potassium-polymer mud filtered through the sand bed with grain sizes from 0.25 to

Table 3. Drilling muds invasion test with 0.25–1.0 mm grain size
Tablica 3. Badania inwazji płuczek w złoże o uziarnieniu 0,25–1,0 mm

			
	Photo 1. Potassium-polymer mud	Photo 2. CBM1 mud	Photo 3. CBM2 mud
Mud invasion into bed [cm]	total	7	2
Filtration through bed [cm^3/30 min]	total	0	0

1.0 mm already after 2 minutes. (Table 3, Photo 1) The tests on the mud filtration into the bed showed that the developed CBM1 and CBM2 muds feature sealing properties and can prevent the mud losses into pores and fissures of coal rocks.

Determination of coal mechanical properties changes under the effect of drilling muds

Ultrasonic tests of coals were performed in the Department of Production Stimulation at the INiG – PIB using an AVS 700 instrument, which is used for dynamic measurements of elastic moduli of rock samples under conditions simulating the reservoir conditions. Tests consisted in determination of acoustic waves speed *P* and *S* in core samples, at the adopted sealing pressure, and calculation on this basis of dynamic moduli of elasticity – Young's *E*, volume *K,* and of Poisson ratio *v*. Measurements of dynamic elastic moduli were carried out for dry coal cores and for the same cores after influence on them of the developed drilling muds. The coal samples were saturated in a special chamber for cores saturation. Coal samples were saturated at a pressure of 0.2 MPa on the bed side with a 3% solution of KCl, and on the borehole side with selected muds at a pressure of 1.8 MPa. The coal cores were saturated with muds up to 72 hours. Tests were carried out at room temperature (approx. 25°C) and at a pressure of 10 MPa.

In general, hard coals feature relatively poor firmness and a large amount of cracks as compared with other rock types (e.g. sandstones or carbonates). This results in the fact that their rock framework is not a material, through which ultrasonic waves propagate easily. The measured values of Young's modulus E for coal samples cut out from one lump in a dry state ranged between 2.3 and 2.9 GPa. The Poisson ratio ranged from 0.28 to 0.35, while moduli of volume elasticity *K* were from 2.2 to 2.6 GPa. (Figs. 2 to 4). Figures 2 to 4 present changes of coal samples elastic moduli under the impact of drilling muds.

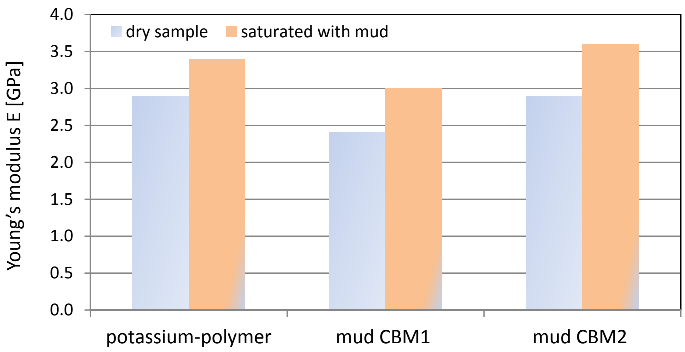

Fig. 2. Effect of selected drilling muds to changes in Young's modulus of samples of coal

Rys. 2. Wpływ oddziaływania wytypowanych płuczek wiertniczych na zmiany modułu Younga próbek węgla kamiennego

An increase in the sealing pressure and pore pressure (when liquid is in the pores) results in an increase in the sample stiffness. This is confirmed by a noticeable growth of moduli of volume elasticity *K* after samples saturation. Both liquids and gases do not transfer shearing forces, so the change of medium in the pore space does not have a significant impact on the wave speed *S*. Measured moduli E in saturated samples have noticeably higher values, which results from an increase in the wave speed *P*.

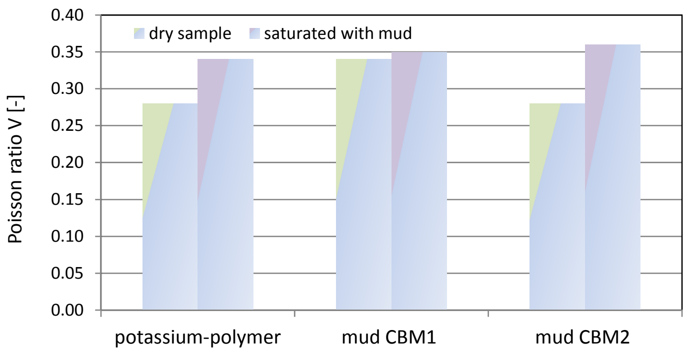

Fig. 3. Effect of selected drilling muds to changes in Poisson modulus of samples of coal

Rys. 3. Wpływ oddziaływania wytypowanych płuczek wiertniczych na zmiany współczynnik Poissona próbek węgla kamiennego

The saturation of pore space of tested coal cores with selected muds in each case resulted in a noticeable increase in Young's moduli E, Poisson ratios v and moduli of volume elasticity K. Also low amplitudes of useful signal against the apparatus noise, characteristic of hard coals (especially during tests on dry cores), could have some impact on the accuracy of measurement results, causing difficulties with determination of the first wave occurrence times.

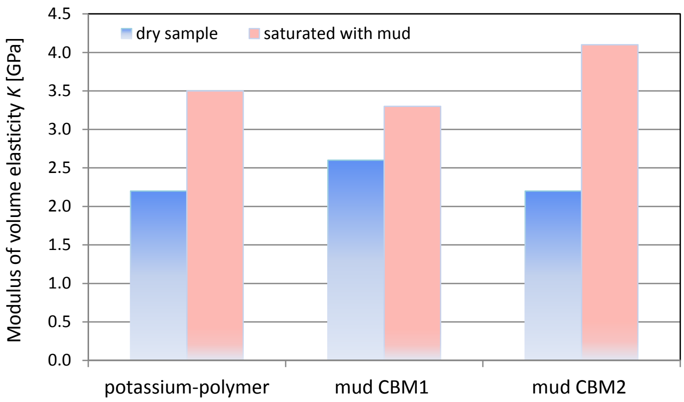

Fig. 4. Effect of selected drilling muds to change the modulus of volume elasticity K of samples of coal

Rys. 4. Wpływ oddziaływania wytypowanych płuczek wiertniczych na zmiany modułu odkształcenia objętości K próbek węgla kamiennego

As a result of potassium-polymer mud action the Young's modulus of coal sample increased from 2.96 to 3.4 GPa (Fig. 2), the Poisson ratio went up by 21.4% (Fig. 3), while the modulus of volume elasticity K by 59% (Fig. 4). The saturation of coal core with CBM1 mud caused also a change of its dynamic elastic modulus. The Young's modulus as a result of saturation increased by approx. 25% (Fig. 2), the Poisson ratio did not substantially change its value, while the modulus of volume elasticity increased its value by approx. 27% (Fig. 4). A similar change of parameters was observed for the coal sample after the action of CBM2 mud with a density of 0.81 g/cm^3. The Young's modulus increased by 24.1% (Fig. 2), and the Poisson ratio by 28.6% (Fig. 3). Instead, the biggest changes was recorded for the modulus of volume elasticity, which went up by approx. 86% as against the value for the dry coal sample. (Fig. 4).

Studies on coals dispersion in the environment of developed drilling muds

The studies on coals dispersion were carried out in the environment of developed muds CBM1 and CBM2, and – for comparison – on the potassium-polymer mud. The carried out studies showed that the coal rock did not disperse in the environment of studied muds. Average values of dispersed coal recovery in the studied samples amounted to 100% (Fig. 5). Because the coal rock does not disperse in water further studies aimed at determination of inhibiting properties of developed muds were carried out on a Miocene shale, featuring highly dispersing and swelling properties.

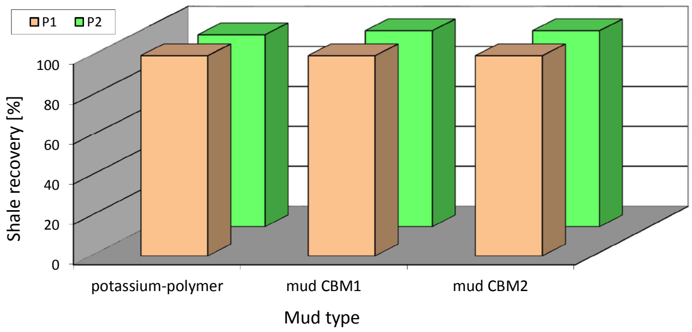

Fig. 5. Values of recovery of coal dispersed in drilling muds

Rys. 5. Wartości odzysku węgla dyspergowanego w płuczkach wiertniczych

The performed dispersive analysis of the Miocene shale in the environment of developed muds confirmed their good inhibiting properties. Recovery values of clayey rock dispersed in the CBM1 mud were approx. 94%, while after dispersion in

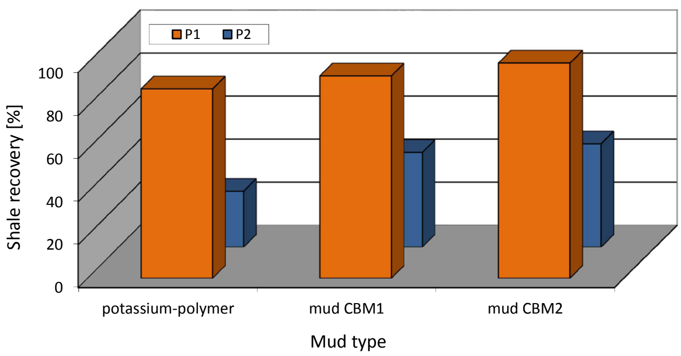

Fig. 6. Values of recovery of Miocene shale dispersed in drilling muds

Rys. 6. Wartości odzysku łupka mioceńskiego dyspergowanego w płuczkach wiertniczych water (P_2) – approx. 44% (Fig. 6). Recovery values of Miocene shale dispersed in the CBM2 mud with a density of 810 kg/m^3 and high values of LSRV viscosity were higher and amounted to approx. 98% (P_1), while after its redispersion in water – approx. 48% (Fig. 6). For comparison, the amount of Miocene shale recovered after its dispersion in potassium-polymer mud was 88%, while after dispersion in water (P_2) – approx. 26% (Fig. 6).

Conclusions

The carried out laboratory tests and the performed analysis of test results allowed to draw the following conclusions:

- The laboratory tests resulted in development of the composition of a mud for development of methane deposits situated in hard coal seams with reduced gradient of the formation pressure. The CBM2 mud (fuzzy-ball type) contains air micro-bubbles as an agent reducing its density. Air micro-bubbles in the drilling mud were produced by its mechanical foaming, using properly chosen surfactants with foaming properties. An appropriate choice of surfactants enabled proper air dispersion and formation in the water phase of micro-bubbles with specified sizes. The developed drilling mud features a density of 810 kg/m^3, contains approx. 22% of air micro-bubbles with half-time exceeding 290 h.
- To drill through highly cracked coal seams with a gradient of deposit pressure exceeding 0.009 MPa/m the composition of CBM1 mud with a density of 1040 kg/m^3 was developed, containing additions enabling effective sealing of rock coal pores. Two types of sealants were applied in the mud composition. The first of them is 'PAP', which task is to seal bigger cracks existing in the coal. The optimum amount of 'PAP' for the drilling mud was determined as 0.1 to 0.3 vol.% against the entire volume of the mud. The second type of agent used in the mud is so-called aluminium complex, consisting of aluminium compounds and humic compounds. This agent task consists in sealing small pores existing in the coal and preventing an increase in the pore pressure of drilled through coal formations.
- The developed CBM1 and CBM2 muds feature good inhibiting properties with respect to drilled coal seams and also to Miocene shale. The coal recovery amounts were 100%, and average values of Miocene shale recovery after its dispersion in mud ranged from 94 to 98%.
- The studies on the pore pressure for coal samples showed that the developed muds CBM1 and CBM2 cause reduction of mud filtrate flow through the core and reduce the increase in the pore pressure by formation of effective sealing on the surface and in the rock pore structure.
- The carried out tests on dynamic elastic moduli of coals showed a noticeable increase in the Young's modulus E, Poisson ratio v, and the modulus of volume elasticity K after acting on them with developed muds.
- The studies on the invasion degree of developed muds CBM1 and CBM2 showed that the muds feature sealing properties and can prevent mud losses in pores and fissures of coal rocks.

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