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IMPACT OF HYDRAULIC FRACTURING OPERATIONS OF COAL SEAMS ON THE ACOUSTIC CLIMATE

ODDZIAŁYWANIE NA KLIMAT AKUSTYCZNY ZABIEGÓW HYDRAULICZNEGO SZCZELINOWANIA POKŁADÓW WĘGLA KAMIENNEGO

In Poland, the economic use of methane from coal seams has been recognized as one of the objectives of the „Energy Policy of Poland until 2030". In Poland at the Upper Silesian Coal Basin, reconnaissance operations were initiated to collect methane from coal seams using drilling wells and hydraulic fracturing operations.

During these operations, noise emission can have a significant impact on the environment. In order to limit the negative impact of noise, well pads are usually located in undeveloped areas. However, in the European Union, the majority of hard coal deposits from which methane can be extracted are located in areas with a high population density.

This article presents the results of noise measurements carried out during hydraulic fracturing operations of coal seams and the results of calculations of the equivalent sound level during the daytime. Based on the analysis of noise emission, some recommendations are given regarding the location of planned new well pads in highly urbanized areas in order to meet the applicable standards of noise protection.

Keywords: coal seams, CBM, drilling wells, hydraulic fracturing, noise emission, noise map

W Polsce ekonomiczne wykorzystanie metanu z pokładów węgla zostało uznane za jeden z celów "Polityki energetycznej Polski do 2030 roku". W ostatnich latach powrócono do prac badawczych nad pozyskaniem metanu z pokładów węgla przy wykorzystaniu otworów wiertniczych realizowanych z powierzchni i hydraulicznego szczelinowania węgla. Takie prace prowadzone na szeroką skalę mogą mieć istotny wpływ na środowisko, a zwłaszcza na zmianę klimatu akustycznego w rejonie wiertni. Problem ten nabiera szczególnego znaczenia zwłaszcza przy realizacji prac poszukiwawczych w rejonie Górnośląskiego Zagłębia Węglowego (GZW), gdzie złoża węgla kamiennego zlokalizowane są w obszarach o wysokim stopniu zurbanizowania.

W artykule przedstawiono wyniki pomiarów hałasu wykonanych podczas hydraulicznego szczelinowania pokładów węgla w rejonie GZW. Prace te były realizowane w porze dziennej przy wykorzystaniu sześciu wysokociśnieniowych pomp o mocy akustycznej 110 dB oraz jednego blendera o mocy akustycznej

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105 dB. Czas trwania zabiegu hydraulicznego szczelinowania wynosił 3 h. Pomiary hałasu wykonano zgodnie z obowiązującymi przepisami prawa, przy pomocy analizatora firmy NORSONIC typ. Nor – 121 z użyciem korelacji spektralnej typu A oraz ze stałą czasową F. Wszystkie pomiary zostały wykonane na wysokości 1,5 m n.p.t., w dniach bez opadów atmosferycznych, w temperaturze otoczenia powyżej 5°C i z założoną na mikrofon osłoną przeciwwietrzną. Przed rozpoczęciem zabiegu oraz po jego zakończeniu zostały wykonane pomiary tła akustycznego.

Na podstawie analizy wyników pomiarów hałasu oraz wykonanego modelowania jego rozprzestrzenienia wykonano mapy akustyczne dla rejonu wiertni.

Słowa kluczowe: metan pokładów węgla, CBM, otwory wiertnicze, hydrauliczne szczelinowanie, emisja hałasu, mapa hałasu

1. Introduction

In recent years, natural gas from unconventional sources have started to play an increasingly important role in the world economy (Krupnicki, 2017). The most important sources of unconventional gas are shale gas, thigh gas and coalbed methane (Suárez, 2012). Coalbed methane is natural gas, which was generated as a result of the transformation process of organic matter into hard coal and has accumulated in coal due to the sorption process (Hadro & Wójcik, 2013; Kędzior et al., 2007).

Global geological resources of coalbed methane are estimated at a level of 100 to 216 trillion m^3, with recoverable resources estimated at 24 trillion m^3. The largest documented recoverable resources of coalbed methane are found in Russia (5.66 trillion m^3), USA (3.96 trillion m^3), Australia together with New Zealand (3.40 trillion m^3), China (2.83 trillion m^3) and Canada (2.55 trillion m^3) (Kuuskraa & Stevens, 2009). In Poland, coalbed methane is found in the Upper Silesian Coal Basin (USCB), the Lower Silesian Coal Basin (LSCB) and in the Lublin Coal Basin (LCB) (Fig. 1). Recoverable resources of coalbed in the USCB amounts to 89.1 billion m^3

Fig. 1. Localization of coal basin in Poland (Jureczka, 2017, modified)

(Kędzior, 2008), in the LCB amounts to only 15 billion m^3 and in the LSCB amounts to 1.75 billion m^3 (Szuflicki et al., 2016).

The coalbed methane is extracted by horizontal or multilateral drilling wells (Naizhong et al., 2012). In order to increase the coefficient of methane extraction from coal seams, multistage hydraulic fracturing operations are carried out (McMilan, 2007). During drilling and hydraulic fracturing operations, noise emission is one of many factors which have an impact on the environment (Hays et al., 2017; Griffiths et al., 2003).

1.1. Coalbed methane extraction technology

Methane in the coal in the sorbed form is kept in equilibrium due to the pressure of the surrounding reservoir waters which fill the natural system of coal cracks (Moor, 2012). Methane flow requires a decrease of reservoir pressure by draining the coal seam. For this purpose, the same technology is used as for natural gas extraction from conventional resources. At the beginning of coalbed methane extraction technology development, vertical wells were used (Flores, 2014). Due to low carbon permeability, the hydraulic fracturing operations were performed to increase gas flow (Zhang, 2014). Another method of extracting coalbed methane was cavitation of coal seams. Figure 2 shows coalbed methane completions using vertical wells.

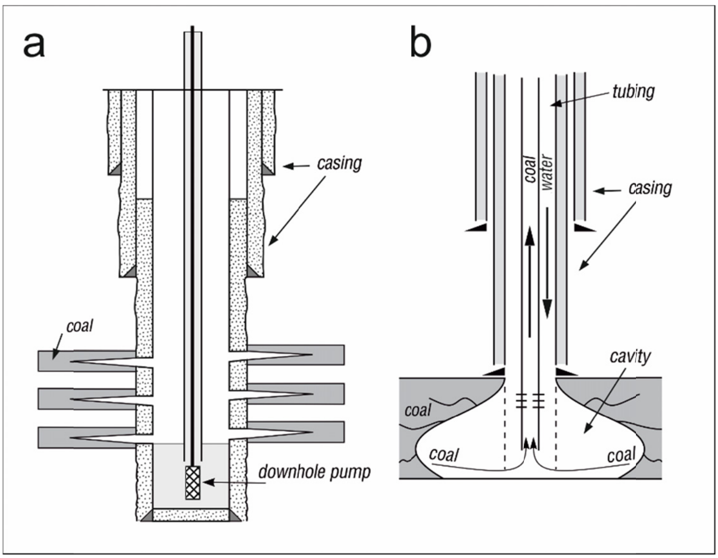

Fig. 2. Coalbed methane extraction using vertical wells; a – perforations with hydraulic fracture stimulation, b – cavitation (Hadro & Wójcik 2013, modified)

With the development of new drilling technology in the oil & gas industry, techniques of coalbed methane extraction were also changed (Nawrat, 2009). Currently, coalbed methane is extracted using horizontal wells (Gonet et al., 2010). By using multi-lateral horizontal wells (Fig. 3) coalbed methane extraction increased from a few to several times, greater flow of methane from coal seams was obtained (Yuan, 2013).

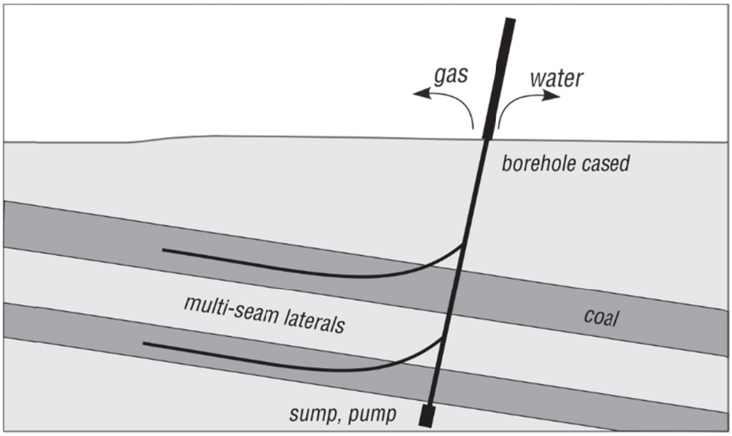

Fig. 3. Coalbed methane extraction using multi-lateral horizontal wells (Hadro & Wójcik, 2013, modified)

Recently, the most common technique of coalbed methane extraction is to use a pair of wells with an intersection point (Fig. 4).

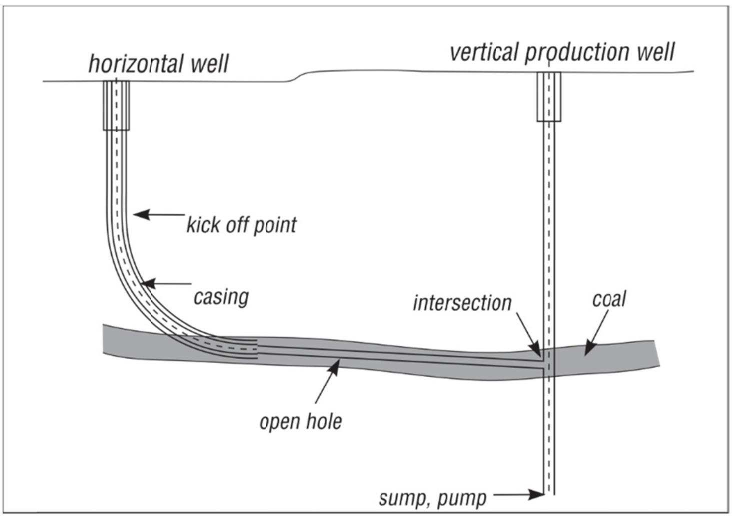

Fig. 4. Coalbed methane extraction using pair of wells with intersection (Hadro & Wójcik, 2013, modified)

In Poland, the first operations related to the extraction of coalbed methane were carried out in the beginning of the 1990's by foreign investors such as Texaco and Amoco (Hadro & Wójcik, 2013). These operations, despite the large financial outlays and the use of advanced research techniques, did not bring the expected results. In 2011-2012, the Australian company Dart Energy resumed work related to coalbed methane extraction in the Upper Silesian Coal Basin. For this purpose, in 2011, the first vertical borehole was drilled to a depth of 1,080 m MD

(1054.5 m TVD). In 2012, a second well was drilled, this time a horizontal well with a depth of 2,300 m MD (856 m TVD) which intersected the vertical well (Jureczka, 2017). The horizontal section was constructed as an open hole and was used for methane drainage from the coal seam (Fig. 5), while the vertical well was used to pump out the reservoir water and as a production well (Hadro & Wójcik, 2013). Conducted field tests showed very low methane flow at a level (Hadro & Wójcik, 2013). In 2016, a consortium consisting of the Polish Oil and Gas Company together with the Polish Geological Institute – National Research Institute, carried out reconstructions of a horizontal section. In order to increase the permeability of coal seams, a five-stage hydraulic fracturing treatment was designed. During the hydraulic fracturing operations under a pressure of 450 bar, a total of 2,590 m^3 of fracturing liquid was injected into the coal seam (Jureczka, 2018).

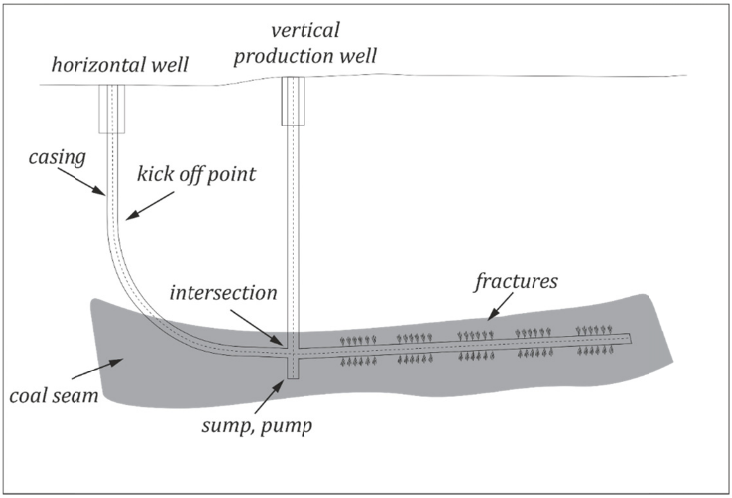

Fig. 5. Coalbed methane extraction in Poland

After multi-stage hydraulic fracturing operations, new field tests were carried out. These tests have shown that the methane flow in the initial testing phase was over 10,000 m^3/d, and stabilized at a level of 5.2-5.4 thousand m^3/d (Jureczka, 2018). It seems reasonable that in future projects related to the extraction of coalbed methane in Poland, multi-stage hydraulic fracturing treatments will also be used.

1.2. Impact of exploration works of coalbed methane on the acoustic climate

During drilling and hydraulic fracturing operations on coal seams, noise emission is one of the significant factors causing an impact on the environment and human health (DeGagne, 2008; Werner, 2015; Hays, 2017). Well pads for conventional and unconventional reservoirs are usually located in undeveloped areas, but in the case of the European Union, the main areas of hard coal deposits from which methane can be extracted are located in areas with high population density. In most countries of the European Union, acceptable noise levels for these areas, during daytime are from 40 to 55 dBA (dBA – weighted decibels), and for night-time from 35 to 45 dBA (EWEA, 2012). In Canada, acceptable noise levels during daytime are from 50 to 66 dBA, while for night-time are from 40 to 56 dBA, depending on acoustically protected areas. In the USA, the permissible sound level for daytime is 55 dBA, while for night-time is 50 dBA (De Gagne, 2008). In most countries, distance between the well pad and noise protected areas should be such that it meets the requirements of acceptable sound levels in given areas. For this purpose, before the commencement of drilling and hydraulic fracturing operations, it is necessary to carry out noise propagation modeling (Łukańko & Macuda, 2016b). Based on noise propagation simulation results, the well pads should be located at a specific distance from acoustic protected areas or mitigation measurement should be implemented to reduce noise emission e.g. noise barrier (Fry, 2013).

In the scientific literature, information is lacking on the noise impact during exploration of coalbed methane. On the other hand, there have been studies showing the impact on the acoustic climate of coal mine methane extraction installations already commissioned (DeGagne, 2008). This paper will discuss the current knowledge regarding noise impact during hydrocarbon exploration from both conventional and unconventional reservoirs.

1.2.1. Impact of drilling operations on the acoustic climate

During drilling operations, the main sources of noise are power generators with sound power level L_{WA} = 105 dB, mud pumps with solid control equipment L_{WA} = 85dB and top drive L_{WA} = 85dB (DEC, 2017). In 2006, Behrens and Associates, Inc. carried out noise measurements during drilling operations. Noise levels were measured for three different well pads at a distance up to 244 m. Average drilling sound levels were 75-87 dBA at 3 m, 71-79 dBA at 61 m, 65-74 dBA at 91 m, 60-71 dBA at 122 m, 56-68 dBA at 152 m, 54-59 dBA at 183 m, 51-55 dBA at 213 m, and 51-54 dBA at 244 m (Behrens and Associates, Inc., 2006). The measurement of noise propagation was also carried out by the New York State Department of Environmental Conservation's Composite (2015) where noise levels at 15 to 610 m ranged from 44 dBA to 76 dBA for horizontal drilling. Research conducted in Colorado by Radtke (2016) during drilling operations in four locations showed that at a distance of 107 meters from the well pad, the average noise level was 65 dBA. Radtke (2016) conducted similar investigations where acoustic barriers were installed around the well pad. The average measured noise level at a distance of 107 meters was 58 dBA. In Poland, noise measurements during drilling operations were carried out by Łukańko & Macuda (2016a). The measured noise at night, corresponding to a permissible noise level of 45 dBA ranged from 223 to 476 m, while for daytime, corresponding to a permissible noise level of 55 dBA ranged from 50-169 m (Łukańko & Macuda, 2016a).

1.2.2. Impact of hydraulic fracturing on the acoustic climate

As previously mentioned, in order to increase the coefficient of methane extraction from the coal seam, it is necessary to carry out hydraulic fracturing treatment. For this purpose, high-pressure pumps are used with the sound power L_{WA} = 110-115 dB and blenders L_{WA} = 105 dB (Łukańko & Macuda, 2016b; NYST, 2015). Depending on the planned size of the hydraulic fracturing treatment, operations are performed using several high-pressure pumps and one blender, which takes about 3 hours (Łukańko & Macuda, 2016b). Noise levels generated during such operations depend mainly on the number of high-pressure pumps used. Using formula 1, it is easy to calculate the total sound power of equipment used for hydraulic fracturing of coal seams (Everest, 2013):

$$SPL_T = 10lg\left(\sum_{j=1}^{n} 10^{0.1SPL_i}\right) \tag{1}$$

where:

SPL_T — total sound pressure level [dB],
$SPLi$ — i-th sound pressure level [dB],
n — number of sound sources.

The decibel values being on a logarithmic scale do not therefore follow the same rules as for linear maths, so for example adding two source of noise at 110 dB doesn't not equal 220 dB. According to the formula 1, if another high-pressure pump (with sound power L_{WA} = 110 dB) is added, the sound level will change according to the values given in table 1.

TABLE 1

Increase in sound pressure level in relation to sound sources (Everest, 2013)

Number of sound sources	Increase in sound power level [dB]	Increase from the previously added source [dB]	Sound power increased for high pressure pump SPL_T [dB]
1	0	—	110.0
2	3.0	3.01	113.0
3	4.8	1.76	114.8
4	6.0	1.25	116.0
5	7.0	0.97	117.0
6	7.8	0.79	117.8
7	8.5	0.67	118.5
8	9.0	0.58	119.0
9	9.5	0.51	119.5
10	10.0	0.46	120.0

Noise measurements carried out by NYDEC (2015) during two hydraulic fracturing operations of shale formation, where 20 high-pressure pumps where used, showed that sound level at a distance of 150 meters from the well pad was from 79 dBA to 84 dBA, while at a distance of 600 meters, from 67 dBA to 72 dBA. Radtke (2016) also conducted noise measurements during hydraulic fracturing of shale rock. At a distance of 107 m from the well pad, the average measured noise level was 67 dBA. During the hydraulic fracturing operation of the shale formation in northern Poland, where 16 high-pressure pumps with sound power level L_{WA} = 110 dB and two blenders (L_{WA} = 105 dB) were used, measurements of noise during the day were carried out (Łukańko & Macuda, 2016b). On the basis of these noise measurements, a noise level of 55 dBA was determined at a distance from the well pad of 200 to 1,300 m, and 45 dBA at a distance of 650 to 1,800 m (Łukańko & Macuda, 2016b).

Analyzing the results of noise measurements during hydraulic fracturing of shale formations, it can be stated that in order to meet noise emission standards during operations for coalbed methane, the location of future well pads should be at a specific distance from the acoustically protected areas (Fry, 2013).

Before initiating exploration operations, noise simulations should be carried out. Based on the results of these simulations, corrective actions should be taken to limit the negative impact of this operation on the environment and human health. In particular, this should be applied to European Union states, where hard coal deposits occur in areas with a high degree of urbanization.

1.2.3. Possibility of noise propagation limitation

In the event that it is impossible to locate the well pad at a suitable distance from the noise-protected areas, mitigation measurements should be implemented in order to keep the sound level standards during the day and night. In the oil & gas industry, the most common solution is the installation of temporary acoustic walls around the well pad (ENC, 2016; Radtke, 2016). For the most effective application, acoustic walls should be located as close as possible to the noise source. In the USA, during drilling and hydraulic fracturing operations for unconventional reservoirs, acoustic screens are used, which can limit the noise propagation from 15 to 22 dB (ENC, 2016). Radtke (2016) showed that acoustic screens reduce the sound level during drilling operations by up to 6 dB, while during hydraulic fracturing by up to 11 dB.

On the well pad many objects can be used as a noise barrier instead of acoustic screens e.g. temporary office and technical containers as well as earth berms (Łukańko & Macuda, 2016a). The correct locations of containers and earth berms can have a significant impact on minimizing noise emissions to the environment.

2. Results of noise measurement and discussion

2.1. Noise emission during hydraulic fracturing of coal seams

Noise measurements were carried out during the first stage of coal seam hydraulic fracturing operations in Poland at the USCB. Six high-pressure pumps with a sound power of 110 dB and one blender with a sound power of 105 dB were used for hydraulic fracturing (Łukańko & Macuda, 2016b). The hydraulic fracturing treatment was carried out during the daytime for a period of 3 hours. High-pressure pumps were driven by diesel Stewart & Stevenson FT-2251T engines – 2,250 BHP and blender with a Stewart & Stevenson MT-132HP engine – 1,450 BHP (Łukańko & Macuda, 2016b).

In the area where the well pad is located, in accordance with Polish environmental law (RMS, 2007), the permissible noise level during a minimum of 8 consecutive hours during the daytime is L_{AeqD} = 55 dB. The acceptable noise level at night in this area, during any 1-hour period is L_{AeqN} = 45 dB.

In order to investigate the noise impact of the hydraulic fracturing treatment of coal seams, 30 measurement points located outside the well pad were selected. Noise measurements were conducted in accordance with ISO 1996-2: 2007; Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels. Measurements were carried out using the NORSONIC type analyzer. Nor-121 with spectral correlation type A and the time constant F. For each measurement the microphone height was 1.5 m above ground level (AGL), measurements were made on days without precipitation, at ambient temperatures above 5°C and with the wind shield attached to the microphone (ISO 1996). Noise measurements were made by sampling methods by measured elementary noise samples at a reference time of 60 seconds (RMS, 2014). At each location of the measurement point, one sample of sound level measurement was made. Before and after the hydraulic fracturing operations, acoustic background was measured. After averaging the measurement results, a value of 40.8 dBA was determined as the acoustic background in the given area.

Based on the obtained noise measurement results in the Surfer program, a map of the noise propagation during hydraulic fracturing was performed. Isophones with values of 45 dBA and 55 dBA are presented on the map, which correspond to the acceptable sound level for night and day in the area where operations were carried out. Figure 6 shows a map of noise propagation during coal seams hydraulic fracturing operations.

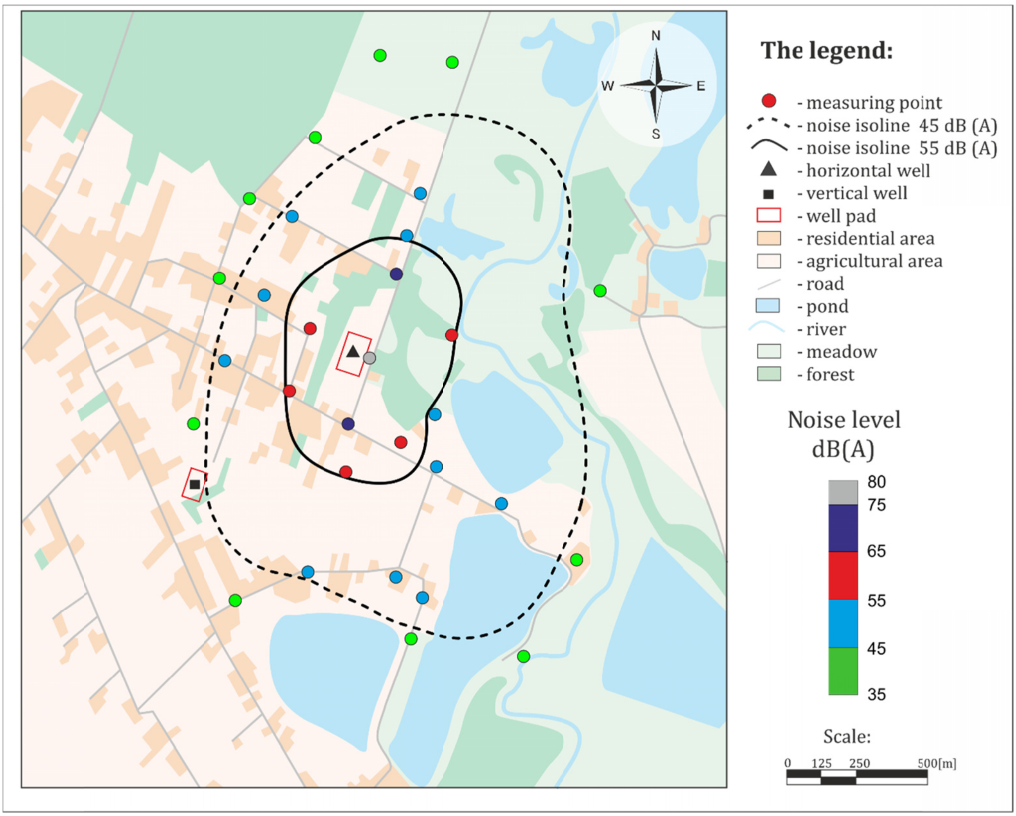

Fig. 6. Acoustic map during hydraulic fracturing of coal seam in USCB

The results of noise measurements carried out during the hydraulic fracturing operation show that the 55 dBA isoline, which corresponds to the permissible sound level for the daytime, had a range towards the north of 950 m, south of 770 m, west of 420 m and east of 650 m. On the basis of noise measurements, the range of the 45 dBA isoline was also determined, which corresponds to the acceptable sound level at night. The isoline had a range of 1,900 m in the north and south-east direction, 1,300 m in the westerly direction and 1,000 m in the westerly direction. The shape of the 55 dBA isoline was caused by the construction of the well pad and the shielding elements which surrounded the well pad, the green belt was located on the east and west side of the well pad. Fang's (2003) research shows that a belt of trees and shrubs can reduce the noise propagation from 2.9 to 6.0 dB.

2.2. Calculation of the equivalent sound level around well pad

Equivalent sound level at a measurement point can be calculated on the basis of determined average noise levels L_{Aek} in particular time intervals with equation 2 (RPME, 2014):

$$L_{AeqT} = 10lg\left(\frac{1}{T}\sum_{j=1}^{m} t_j 10^{0.1L_{Aekj}}\right) \tag{2}$$

Substituting the relevant data to equation 2, received:

$$L_{AeqD} = 10lg\left(\frac{1}{T}\left(\left(t_1 \times 10^{0,1\times L_{Aek1}}\right) + \left(t_2 \times 10^{0,1\times L_{Aek2}}\right)\right)\right) \tag{3}$$

where:

m — time intervals t_p,
L_{Aek1} — measured noise level at specific point (dBA),
L_{Aek2} — acoustic background (dBA),
T — reference time for day (s),
t_1 — duration of hydraulic fracturing (s),
t_2 — duration of acoustic background (s).

Parameter L_{AeqT}, calculated with equation, corresponds with the noise index (RMS, 2014):

- L_{AeqD}, if parameters and calculations were referred to reference time $T = 8$ hrs (28,800 s) during the day (6:00-22:00),
- L_{AeqN}, if parameters and calculations were referred to reference time $T = 1$ hr (3,600 s) at night (22:00-6:00).

Following equations (2 and 3) in order to calculate equivalent sound level during day time at specific measurement point, two L_{Aek} values should be taken for further calculations: the first L_{Aek1} – value of noise level measured during the hydraulic fracturing operation at the measurement point, the second L_{Aek2} – acoustic background. A reference time $T = 28,800$ s has been adopted in accordance with the provisions of environmental law, while the duration of the hydraulic fracturing treatment $t_1 = 10,800$ s, and for the background $t_2 = 18,000$ s. Acoustic background has been adopted at the same level for all study area. For example, at the point where measured noise level was 66.6 dBA, calculated equivalent of noise level for day time was 62.4 dBA. Table 2 presents calculations of the equivalent noise level calculated for day time for the area in which hydraulic fracturing operations were carried out.

TABLE 2

Equivalent sound level calculation L_{AeqD} for day time around well pad

Measured noise level	Acoustic background	Calculated equivalent sound level for day time	Difference between L_{Aek1} and L_{AeqD}
L_{Aek1} [dB]	L_{Aek2} [dB]	L_{AeqD} [dB]	ΔL [dB]
66.6	40.8	62.4	4.2
58.9	40.8	54.8	4.1
76.4	40.8	72.1	4.3
55.2	40.8	51.2	4.0
55.1	40.8	51.1	4.0
65.3	40.8	61.1	4.2
61.1	40.8	56.9	4.2
55.2	40.8	51.2	4.0

For equivalent sound levels, new acoustic maps were prepared using Surfer software. Figure 7 shows the difference between results of noise measurement and calculate equivalent sound level for day time.

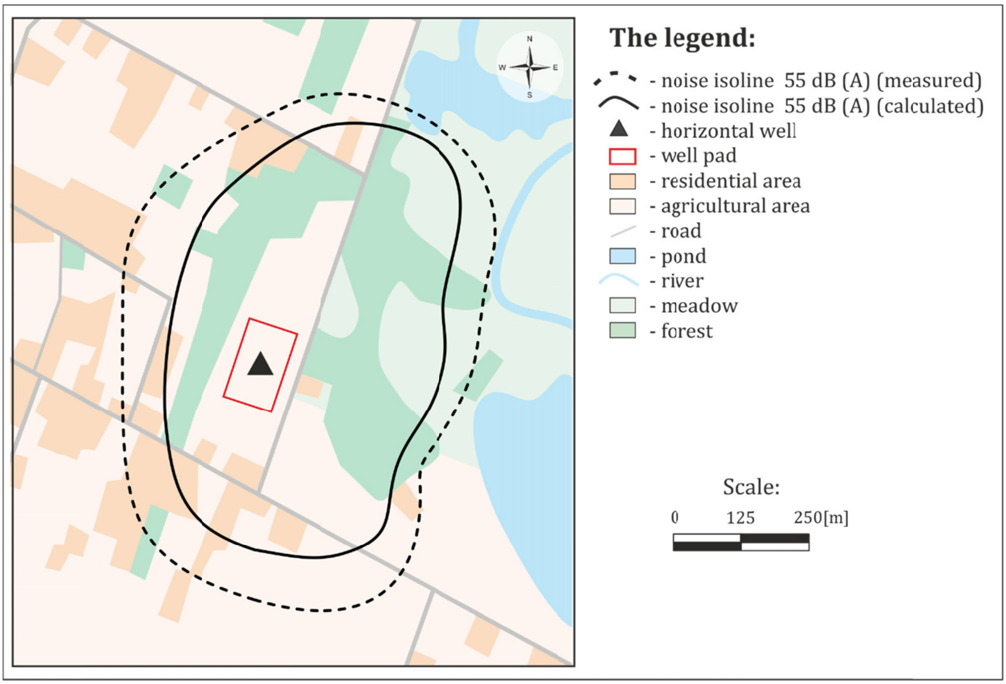

Fig. 7. Acoustic map during hydraulic fracturing of coal seam (day time, 6:00-22:00)

From the analyzed results of calculations of the equivalent sound level in eight measurement points, where the measured noise during hydraulic fracturing was above 55 dBA, it appears that the sound level decreased by an average of 4.13 dB and the range of the 55 dBA isoline decreased from 60 to 180 m. Calculated to an equivalent sound level corresponding to 8 hours, the 55 dBA isoline had a range of 890 m to the north, 535 m to the south, 570 m to the east and 240 m to the west. The calculations demonstrate that in acoustically protected areas located around the well pad, during the hydraulic fracturing operation, acceptable sound levels for the day time were exceeded.

3. Conclusion

The exploration of coalbed methane is most often carried out with a horizontal well. In order to increase methane recovery from the coal seam, hydraulic fracturing operations are performed, which are accompanied by an increased noise emission. This noise is generated primarily by high-pressure pumps used for hydraulic fracturing treatment. As demonstrated by research carried out for the purposes of implementation of this article, an isoline range of 55 dBA, the permissible sound level in the daytime during the hydraulic fracturing procedure ranged from 240 m to 890 m. The maximum sound level of 76.4 dBA was measured at a distance of 65 m from the borehole. The shape of the terrain, in particular tree belts occurring on the eastern and western sides of the well pad, had a large influence on sound propagation during the operations.

In order to verify that emission standards have been met during the implementation of hydraulic fracturing procedures, modeling of noise propagation should be performed for the area of interest. In the event of non-compliance of noise standards, corrective measures should be taken to limit sound emissions. The most commonly used elements in the oil & gas industry are temporary acoustic walls. From the literature, it appears that the use of acoustic walls during hydraulic fracturing operations can reduce noise by up to 11.0 dB.

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