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THE INFLUENCE OF PROSPECTING UNCONVENTIONAL HYDROCARBON RESERVOIRS ON ACOUSTIC CLIMATE**

1. INTRODUCTION

Drilling technologies used for unconventional gas prospecting, especially when shale formations are involved, do not much differ from the ones used for conventional gas deposits, when hydraulic fracturing operations are performed. The most important differences are related to the social acceptance of the scale of the undertaking. Among the most important ones are the density of drilling sites as well as the number and magnitude of hydraulic fracturing operations which generate great quantities of production waste. When the unconventional gas deposits are lying deep, the hydraulic fracturing operations may potentially affect aquifers with useful water. In Poland the depth of prospecting drilling for unconventional shale gas ranges between slightly above 2,000 to 4,500 m. Drilling to such depth requires rigs of high hoisting capacity and high installed power capacity of master motors which power rig subassemblies. The operation of such systems also creates environmental noise hazard, especially in the close vicinity of the rig. The effect of drilling operations on the acoustic environment depends on a number of factors. Among the most important ones are the location of the rig, depth of the well, rig type, power capacity of installed motors, power capacity of mud pumps, number of mud shakers, type of noise barrier applied for the rig, urbanization of the rig area and vulnerability of particular elements of the environment to pollution [11].

2. IDENTIFICATION OF NOISE SOURCES IN THE RIG

Drilling of prospecting wells for shale gas is most frequently realized with the rigs, the subassemblies of which are powered by electrical motors of total power 2,500 to

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4,000 kW [10]. The energy comes from sets of mobile high-pressure and high power generators. The number of power generators and their total power are selected each time on the basis of power balance of particular technological subassemblies and the emergency power supply.

The risk analysis of drilling operations described in literature [2, 11] shows that power generators, mud pumps and mud shakers have the biggest influence on the acoustic environment around the rig.

3. METHODICS OF MEASURING ENVIRONMENTAL NOISE

The reference methodics of measuring environmental noise generated by installations or utilities was presented in the Environment Minister regulation of 30 October 2014 concerning requirements with regard to measuring emission volumes and measuring the quantity of collected water (Official Journal 2014, item 1542) [9].

According to the regulation, the measurement points should be localized with respect to the site, the technical characteristic of the noise sources, absorbing and reflecting properties of the terrain and the way in which it has been managed [9]. In the noise-protected areas the measurements should be realized in such places where the area of strongest impact can be indicated. When analyzing noise emission in such areas, the microphone should be placed 1.5 m over the ground in undeveloped areas, and 4 m ± 0.2 m over the ground surface or in the opening of a window a floor exposed to noise in developed areas [1, 4–6, 9]. When measurements are performed near buildings, the microphone should be disposed 0.5 to 2.0 m from their front walls [1, 4–6, 9].

According to the guidelines presented in literature [1, 4–6, 9] the analyses of environmental noise should be performed with the use of a measuring kit, which meets the requirements of integrating or integrating-averaging meters. The measuring kit should contain a sound level meter and calibrator of accuracy level equal to 1. These apparatuses should also have a calibration certificate (expiry after 24 months at most) and a validation certificate issued by an accreditation office. The measuring microphone should be equipped with windshield, regardless of the meteorological conditions [9].

In compliance with the rules discussed in literature [9], the environmental noise should be measured at least 3.5 m above the terrain surface for the following admissible values of meteorological parameters:

- temperature −10°C to 50°C,
- humidity 25% to 90%,
- average wind speed to 5 m/s,
- atmospheric pressure 900 hPa to 1,100 hPa.

According to the guidelines presented in literature [1, 4–6, 9], the noise level is recorded continuously in the reference time T or elementary noise samples in the reference time T (the sampling method).

The noise level generated during drilling operations does not significantly change in time, therefore the sampling method is most frequently used. It is used when in the reference time T the source emits noise to the environment in identifiable time intervals t_p, with a differing sound on a set level L_{Ak}. In such conditions the noise level should be measured with frequency characteristic A and time weightings F (Fast) [1, 4–6, 9]. These criteria are selected on the basis of the work characteristic of a given source of noise and the acoustic background of the environment.

The time of measurement $t_{o,}$ needed for determining the sound level in the sampling method is defined on the basis of rules presented in literature [9]:

– t_o = 60 s, during constant noise measurement in time, when the noise level does not exceed 5 dB,
– t_o = 10 s, when constant noise measurement in time is hindered by periodical phenomena evoking noise on a higher level than expected. This mainly applies to the noise generated by traffic, flying airplanes, and the intervals between these emissions are insufficient to perform 60 s measurements,
– t_o equals to the duration of a noise emission event or its multiplication – when the source is active periodically,
– $t_o \geq 5$ min for noise of varying noise level in time t_p.

The number of n elementary noise samples is currently established in the measuring point, in compliance with the requirements specified in Table 1.

Table 1

Number n of required elementary noise samples, depending on a difference R between the highest and the lowest measured value of noise level of a sample in a given time interval t [9]

Difference R [dB]	$0 < R \leq 1$	$1 < R \leq 1.5$	$1.5 < R \leq 2$	$2 < R \leq 2.5$	$2.5 < R \leq 3$
Number of measurements n	3	4	5	6	7

The duration of the measurement should be elongated when the difference between parameters exceeds 3 dB. The average sound level L_{Asr} is calculated from formula 1 [9]:

$$L_{Asr} = 10\lg\left(\frac{1}{n}\sum_{k=1}^{n}10^{0.1L_{Ak}}\right) \tag{1}$$

where:

n – number of samples in the measuring series,
L_{Ak} – measured sound level in time t_o (result of measurement of a noise sample) [dB].

If the noise level emitted by a rig to the environment is to be defined correctly, one should also measure the acoustic background L_{At} in the work place. In literature [9] the authors recommend performing measurements on the same time of the day and in similar meteorological conditions in which noise level generated by analyzed sources has been measured. When hydrocarbon exploration works are performed, both conventional and unconventional sources, the measurements should precede before construction of the well pad.

For determining the noise level L_{Aek} in time interval t_p the average level of acoustic background L_{At} should be subtracted from the average sound level L_{Asr} expressed with formula (2) [8].

$$L_{Aek} = 10\lg\left(10^{0.1L_{Asr}} - 10^{0.1L_{At}}\right) \tag{2}$$

where:

L_{Asr} – average noise level for time interval t_p or average sound level for a given source [dB],

L_{At} – average level of acoustic background [dB].

4. INFLUENCE OF DRILLING OPERATIONS ON ACOUSTIC CONDITIONS

For the evaluation of the effect of drilling operations on the acoustic conditions around the well pad, the environmental noise was measured (granted a concession for unconventional hydrocarbon prospecting) in the north of Poland. According to the Regulation of the Environment Minister of 14 June 2007 about the concerning acceptable noise levels in the environment (Official Journal No. 120, item 826) [8], the areas to be prospected were qualified as areas of residential development of multi-family dwellings, recreation areas beyond the city area, farm building sites (agricultural)and residential and commercial areas [3]. According to this regulation the acceptable noise level A expressed in dB for these areas equals to [8]:

– 55 dB for the day time – time interval equal to 8 least preferred hours of a day following,
– 45 dB for the night hours – time interval equal to 1 least preferred hour at night.

Description of the prospected area

Drilling operations were performed in the area used for agricultural purposes. The well pad was located at 178 m a.s.l. and was inclining eastwards (Fig. 1).

At a distance of 320 m from the well pad in the southwestern direction there was an acoustically protected area, i.e. farm building sites. The closest residence area was at a distance of ca. 550 m, and a deciduous forest at a distance of about 50 m.

The well pad was partly protected with an earth berm artificially formed of the top soil humus taken off the well pad at the initial stage of build (ca. 3.5 m high). Figure 2 illustrates the way in which the area was managed and the place where the earth sound barrier was disposed. The noise is additionally screened by containers up to 3.0 m high.

Characteristic of major noise sources

Drilling operations were performed with the use of a rig MASS 6000E. The following subassemblies (major noise sources) were used (Fig. 3): three power generators KATO – 1,600 KM each (1), Top Drive PTD-500 (2), three mud shakers SWACO Mongoose (3) and two mud pumps T1300 – 1300 KM (2). The power generators operating in the rig were placed in a noise-insulated casing, whereas mud pumps and mud shakers had no noise-insulation around them. The major noise sources on the well pad are listed in Table 2, with type and noise power indicated.

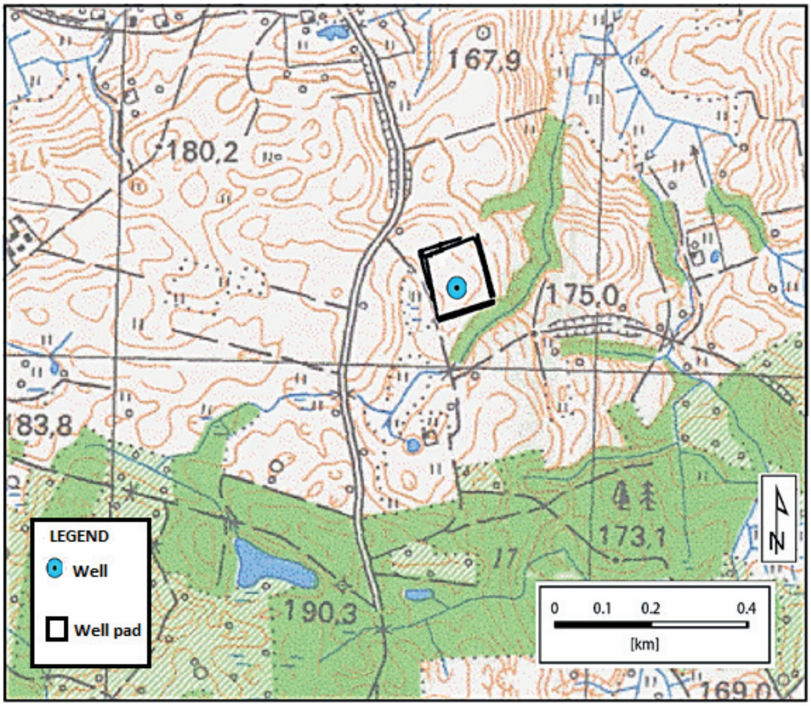

Fig. 1. Map of well pad localization [3]

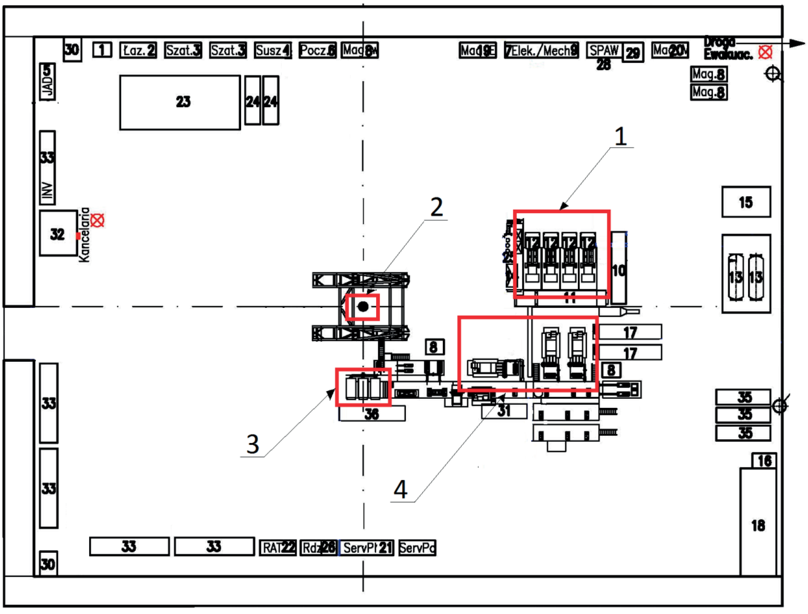

Fig. 2. Localization of noise barriers on the well pad [3]

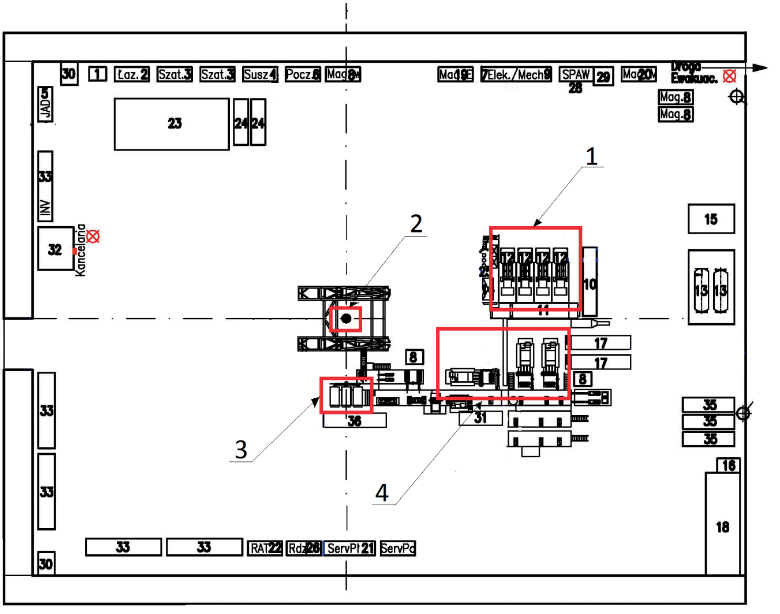

Fig. 3. Localization of noise sources accompanying drilling operations [3]

Table 2

Characteristic of noise sources while performing drilling operations [3]

No.	Source	Number	Type	Level of sound power [dB]
1	Power generators KATO 1600KM	3	Source – building	102
2	Top Drive PTD-500	1	Point – all directions	90
3	Shakers SWACO Mongoose	3	Point – all directions	90
4	Mud pumps T1300	2	Point – all directions	90

Measurement of environmental noise

Prior to the measurement of noise emission from drilling operations during the prospecting of the shale gas, there were selected measurement points, where the environmental noise level was established for the day and night hours. The noise level was measured in 32 point localized at various distances from the drilled well and staying within the interval of 50 m to 400 m [3]. The noise measurements were performed both on the well pad (eight measuring points localized close to the major noise sources) and also beyond it (24 measuring points distributed radially).

The environmental noise was measured with the use of a sound analyzer Sonopan SON-50 of accuracy class 1, with a valid validation certificate. The measuring microphone was equipped with a windshield. Prior to the environmental noise measurement, the device was calibrated with a calibrator of accuracy class 1. During noise measurement the atmospheric conditions were also established with the use of a mobile meteorological station. The measured meteorological conditions are presented in Table 3.

Table 3

Meteorological conditions accompanying noise measurement while drilling [3]

Measured parameter	Day time	Night time
Wind speed and direction	1.1÷2.7 m/s, western	2.1÷4.3 m/s, western
Temperature	13.5°C	14.5°C
Humidity	72%	73%
Atmospheric pressure	994 hPa	990 hPa

The noise was measured with the sampling method during which elementary noise samples were recorded in reference time T = 60 s. Three sound measurements were performed in each measuring point. The average value was assumed to be the final result. During the environmental noise measurements with a time weightings F 'Fast' and a frequency characteristic A, the microphone was placed 1.5 m above the ground surface. Prior to the discussed environmental noise measurements there was also measured the sound background level, which equaled to L_{At} = 32.5 (dB) for day time, and L_{At} = 29.6 (dB) for night hours [3]. The sound background level was measured at a distance of 3 km to the north from the rig site. The sound background measurement point was localized in the village the drilling operations were performed. It was so selected as to have similar acoustic conditions as the rig area (agricultural lands were localized close to a forest).

Results of environmental noise measurements

Noise level was measured on the well pad in eight point at a distance of 50 m from the drilled well. The highest environmental noise emission accompanying drilling operations equaled to L_{Ak} = 85.2 dB for day time and L_{Ak} = 85.3 dB for night hours [2]. The measuring point where the highest noise level was measured was localized close to the power generators. The measured sound level during the night and day was very similar and differed only by 0.1 dB. The measurement point on the well pad, where the noise level was lowest, was localized at the entrance to the well pad and equaled to L_{Ak} = 57.1 dB for the day time and L_{Ak} = 57.2 dB for the night hours [3].

Apart from this, 24 measuring points were localized beyond the well pad at a distance of 100, 200 and 400 m. The measuring point, where the measured noise level was lowest, was localized at a distance of 400 m from the well to the east. The measured noise level equaled to L_{Ak} = 36.3 dB for the day time and L_{Ak} = 34.7 dB for the night hours, respectively. The highest measured noise level was measured at a point localized 400 m from the rig to the east and equaled to 46.2 dB for the day time and 45.4 dB for the night hours [3].

A map of the noise distribution around the well pad was performed on the basis of the obtained results of measurements using the Surfer software, where the isophone contours determined for the sound level equaled to 55 dB for the day time and 45 dB for the night hours.

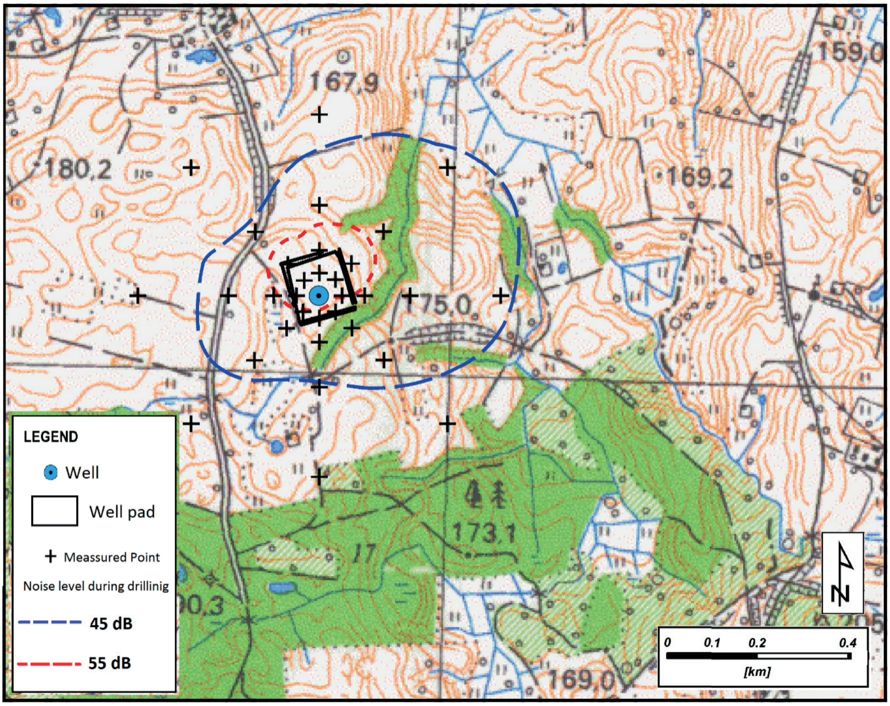

Fig. 4. Map of noise around the rig while performing drilling operations [3]

The analysis of Figure 4 reveals that the isophone contour 55 dB corresponds to the acceptable sound level for the day time and is practically limited to the well pad, and mainly extends to the east. The noise was emitted by the power generators and there were no berms or containers, which would play the role of sound barriers. The isophone contour 45 dB, which corresponds to the acceptable sound level for the night hours, also extends towards the east. The sound protected areas were beyond the reach of isophone contour 55 dB for day time and 45 dB for the night. The analysis of the obtained results of environmental noise measurements reveals that shale gas-oriented drilling operations do not have a significant impact on the sound conditions in the residence areas and farm building sites.

5. CONCLUSIONS

The analysis of noise emitted by the rig MASS 6000E while drilling a shale gas well prompts the following conclusions:

1. Noise emitted by particular rig subassemblies differs and mainly depends on their power capacity, type of work and sound protection.
2. The influence of drilling operations on the noise emission in the closest neighborhood of the well pad mainly depends on the number and localization of the dominant sources of noise, degree to which they are blocked by technological installations and auxiliary equipment, and the density of development of the area.

3. Depending on the development of the well pad and form of the sound barriers, the isophone contours may assume an elliptical shape in the closest vicinity of the well pad, and circular at bigger distances from the well pad.
4. The average coverage of the isophone contour 45 dB, the most frequent admissible value in areas where prospecting drilling is performed during the night, ranges between 223 and 476 m; the coverage of isophone contour 55 dB for the day time hours totals to 50–169 m.
5. The required reduction of noise generated by the dominating sources (i.e. the noise level does not exceed 45 dB at a distance of 100 m from the rig) ranged from 1.1 to 13.1 dB for the night hours 4.3 dB for the day time. Such a reduction can be hardly obtained because of the requirements set before the rig subassemblies, which should be lightweight and easily mountable,
6. In some localizations, where residence areas are localized close to the planned well pads, the rigs can be oriented towards them to make use of the noise barrier and reduce the noise from dominant sources.

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