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RESEARCH ON THE ENVIRONMENTAL IMPACT OF INDUSTRIAL NOISE EMITTED BY MINE AND MINING PLANTS

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Abstract:
The article presents the results of measurements of environmental noise accompanying the operation of devices operated in surface facilities of hard coal mines and noise generated in technological processes related to the loading and transport of spoil and materials necessary for production. The research results presented in the article are part of the program of "Consequences of excessive noise in the mining environment of hard coal mines", the overarching goal of which is to reduce the emission of industrial noise. The research described in the article, carried out using the sampling method, was introduced in order to determine the actual values of noise levels emitted to the external environment from mines and mining plants, as well as to identify the acoustic power levels of devices and processes constituting the main sources of noise in mines. The obtained results showed that mines and mining plants are often not fully aware of the scale of the environmental impact of undesirable noise they emit. Therefore, the current periodic measurements of environmental noise should be replaced with permanent monitoring, which will be beneficial not only for the environment, residents of housing estates located near mines, but also for the mining plants themselves.

Key words: *mining technological processes, mine, noise, environment, hazard, mining plant*

INTRODUCTION

According to the European Environment Agency (EEA) [1], it is estimated that 113 million people in Europe experience continuous day and night long-term noise levels above the limit values for urban areas. Among the most burdensome sources of noise for humans, the following should be distinguished: car, rail and air traffic as well as industrial sources operating continuously or "temporarily" for over a million inhabitants of factory premises and over 5 million workers employed in industrial plants [2, 3, 4]. Noise pollution is also a serious health problem, but we are not always aware of how it affects our health. According to the World Health Organization (WHO) [5], long-term exposure to environmental noise with values between 60-75 dB can lead to negative cardiovascular and metabolic effects, causing up to 12,000 premature deaths and 48,000 new cases of ischemic heart disease annually in Europe. The noise intensity of the order of 55 dB leads to reduced efficiency, chronically high irritability in 22 million people and high sleep disturbance in 6.5 million Europeans [6, 7, 8]. To limit these negative phenomena, the European Union is taking several initiatives to reduce environmental noise, the most important of which are the EU Directive on Environmental Noise [9] and the Seventh General EU Environmental Action Program [10]. Unfortunately, these ambitious goals are not always achievable, as was also experienced by Poland in 2021, which faced the Court of Justice of the European Union due to failure to meet the obligations arising from Directive 2002/49/EC in the field of noise emissions [11, 12].
According to the Chief Inspector of Environmental Protection in reports on the state of the environment [13], in Poland road traffic noise greater than 60 dB occurs on over 60% of the length of national roads and on 92% of the length of interregional roads, and the noise caused by rail traffic is greater than 60 dB during the day and 50 dB at night on nearly 65% of railway routes. Moreover, around industrial plants, the average daily noise levels are 50-90 dB [14]. Employees of the Department of Safety Engineering of the Silesian University of Technology, as part of the research project "Consequences of excessive noise in the mining environment of hard coal mines" decided to take a closer look at this phenomenon and assess the impact of industrial noise generated during technological pro-

cesses taking place in the mine on the external environment, especially residential buildings, and propose solutions enabling monitoring and reducing this risk.

LITERATURE REVIEW

The exploitation of hard coal in Poland is a complex and multi-stage process, based mainly on deep mining, where the extraction takes place through at least two vertical shafts: the intake and exhaust shafts, which transport the output (hard coal and waste rock) from the mining walls and longwalls through the network mining excavations to surfaces for coal mechanical processing plants, where, after pre-treatment, enrichment and sorting, hard coal is prepared for rail and road transport. Research conducted in recent years by the Department of Safety Engineering at the Silesian University of Technology with project partners, the company ACS Słuchmed Sp. z o. o. from Lublin and the Central Laboratory for Work Environment Research "Stanisław Bielaszka" from Jastrzębie Zdrój have shown that the entire technological process related to hard coal mining is burdened with high emission of excessive noise affecting not only miners, but also the environment [15, 16, 17, 18, 19]. The main sources of noise in the conditions of underground hard coal mines are, among others: blasting works; mining machines (longwall shearers, plows, roadheaders); underground track locomotives and overhead diesel rail tractors; main drainage equipment and installations; electric and air duct fans; pneumatic drills; belt conveyors; scraper conveyors, billet crushers and many other tools, machines and devices [20, 21, 22, 23], which emit noise with A sound levels from 75 dB to 120 dB, and sometimes even more. It is related to the specificity of underground working conditions and technological requirements. Due to the depth of the exploitation processes performed, this noise does not have a significant impact on the external environment, except for the main fans station, which forces air to circulate through the mine workings, and the built-in surface devices generate noise that may be harmful to the environment [24, 25].

The mining plant, the mine, however, is not only the underground infrastructure, but also basic facilities built on devices with mining equipment, which include: an intake shaft with a main fan station, a mining (skip) shaft connected with a coal mechanical processing plant and a railway siding; lamp house facilities, post office, switching station and medium voltage; methane drainage and stations; administrative and office buildings; settlers; coal storage site; wood float; material and fuel depots, etc. (Figure 1).

In most of these facilities, 24/7 technological processes related to the normal functioning of the mine are carried out in the system of 24/24, which to a greater or lesser extent emit noise to the environment all the time, contributing to the deterioration of the acoustic climate in the mine's surroundings. The characteristics of noise differ in the frequency range and directivity of its source, which is why the aspects of knowing it are so important [26, 27, 28].

Fig. 1 Mine surface infrastructure facilities Y

The main noise-generating processes in mines that significantly affect the level of acoustic emissions to the environment include:

- ventilation of mining excavations with the use of main ventilator stations,
- loading, transport and unloading of coal and waste rock from below to the surface by means of skips and shaft devices,
- transport of output (spoil) from the shaft to the coal mechanical processing plant with a network of surface belt conveyors,
- coal processing and enrichment in a mechanical processing plant,
- loading of sorted and enriched coal onto railway wagons and cars,
- road and rail freight forwarding of coal and materials needed to ensure the continuity of mine production,
- coal storage in dumps,
- loading and unloading of materials necessary to maintain production on the mine site,
- operation of shaft devices,
- machines and devices carrying out production processes inside surface facilities of mines from which the noise comes out through facades with low acoustic insulation.

RESEARCH METHODOLOGY

In order to assess the scale of this phenomenon, the Department of Safety Engineering of the Silesian University of Technology in cooperation with the Central Laboratory for Work Environment Research "Stanisław Bielaszka" for over two years has been conducting research on noise emitted by machines and devices of hard coal mines in octave bands in the range of 31.5-8000 Hz to determine the actual exceedances of sound limit values at the workplace and in the environment. These tests were inspired by the results of the hearing screening test carried out in 2018-2019 in cooperation with the company ACS Słuchmed Sp. z o. o. from Lublin on a group of 3265 active and former employees of Silesian and Lesser Poland mines, which confirmed the negative impact of industrial noise generated by mines and mining plants on the organ of the average miner's hearing and the scale of this phenomenon.

Three hard coal mines located near municipal buildings in the Silesian Voivodeship were selected to present the results of this article. Due to limitations in the use of proper names, the names of the mines for the purposes of this article have been hidden under the designations X, Y, Z.
To properly identify the most important sources of noise emitted by the noise-generating processes of selected hard coal mines to the external environment, a number of activities were carried out to enable the proper implementation of the research, among which one should mention:

- conducting a local inspection of the area of selected hard coal mines, where the research area and the range of noise limit values in the acoustically protected areas around the mine were determined,
- determination of representative control points in acoustically protected areas around the mine enabling the performance of control measurements of the A sound level,
- an inventory of the main noise sources in the mines, combined with the measurements of their acoustic emissions,
- determining the range of acoustic impact of mines in areas with residential buildings,
- indication of noise sources in the mines responsible for exceeding the limit values at the observed control points.

CHARACTERISTICS OF RESEARCH OBJECTS

After conducting an on-site visit, three mines with similar infrastructure and location in relation to residential buildings were selected for research to compare the results of environmental noise measurements. In these mines in the main plant, the same main sources of noise were selected for comparison purposes:

- preparation plant,
- mining, downhill and material shafts,
- conveyor belts transporting coal to the preparation plant,
- a railway siding intended for loading coal,
- place of coal storage.

Example results of acoustic measurements of the main noise sources located in the facilities of the surface part of mines are presented in Table 1.

Table 1
Examples of noise sources in X, Y, Z mines

No.	Mine plant	Noise source	Average sound pressure L_A, [dB]									
			L_{Aeq}	Octave frequency band, [HZ]								
				31.5	63	125	260	500	1000	2000	4000	8000
1.	X	coal crusher	101.5	61.1	68.5	78.9	87.4	93.1	97.8	95.6	91.8	81.1
	Y		102.5	63.5	69.8	79.1	88.3	95.2	96.4	97.3	92.4	83.9
	Z		98.2	60.9	63.2	75.4	79.2	91.3	93.8	92.1	89.6	84.1
2.	X	screen	97.7	60.7	70.5	79.7	87.3	93.6	95.9	93.1	85.5	74.1
	Y		102.5	57.3	67.7	78.1	87.6	95.2	98.1	97.7	91.2	83.2
	Z		96.1	51.1	65.5	72.6	82.5	85.7	89.3	90.1	91.9	76.9
3.	X	conveyor belt	90.5	53.2	65.6	75.2	77.1	82.9	85.2	85.4	81.7	72.0
	Y		92.9	51.2	53.1	72.3	75.0	89.3	89.1	82.3	77.3	66.9
	Z		88.4	41.4	45.3	54.4	70.8	76.2	86.2	83.1	70.2	58.8
4.	X	turnstile	86.0	60.4	68.7	76.7	76.9	81.2	80.3	73.8	73.4	69.5
	Y		87.1	66.3	72.5	76.3	77.4	80.2	83.3	78.4	69.6	62.4
	Z		95.5	54.2	62.8	76.1	84.1	88.0	88.7	89.7	88.5	84.0
5.	X	gantry crane	94.4	52.2	66.9	73.3	80.9	85.7	88.4	90.0	85.5	83.0
	Y		91.6	54.3	64.6	73.5	80.8	84.4	85.9	85.8	83.2	77.6
	Z		90.1	58.5	63.5	65.8	70.7	75.9	84.1	85.9	83.5	79.8
6.	X	hoisting machine	111.2	49.4	53.3	69.4	86.4	91.9	98.8	104.4	105.7	107.7
	Y		110.8	64.2	80.7	95.5	105.1	106.3	104.1	98.6	95.1	97.6
	Z		109.5	58.3	72.2	87.3	97.8	99.1	98.0	99.7	105.9	102.9
7.	X	skip equipment	96.6	45.0	49.7	62.0	72.8	88.6	90.2	91.0	91.6	81.0
	Y		92.0	54.1	54.2	61.1	71.3	81.9	90.2	83.2	81.9	73.3
	Z		93.3	46.1	49.1	54.3	71.7	85.0	88.8	88.1	85.0	80.3
8.	X	carts tipping machine	102.0	55.0	65.1	82.2	93.7	99.6	94.1	91.4	86.0	73.3
	Y		94.0	52.9	55.9	67.0	71.9	88.0	89.5	89.4	78.3	76.2
	Z		95.7	62.1	65.9	69.4	75.8	90.2	91.6	90.4	80.1	70.6
9.	X	shunter	100.7	76.9	77.6	79.8	84.6	90.6	94.2	94.1	96.1	89.7
	Y		103.3	62.7	73.3	79.3	86.8	96.0	100.1	96.4	93.5	79.7
	Z		98.3	60.1	63.5	70.1	76.8	86.5	94.5	92.8	91.1	83.5
10.	X	loading of wagons	91.1	57.1	65.4	71.2	78.4	85.1	86.2	85.1	80.2	75.6
	Y		89.9	45.6	48.2	56.4	71.3	81.4	88.1	82.1	71.2	60.3
	Z		90.5	47.2	54.8	71.2	72.1	80.1	80.7	85.3	85.3	83.1
11.	X	mine loaders	97.1	56.1	66.6	75.9	84.3	86.1	90.9	90.0	93.2	77.6
	Y		92.4	59.8	60.1	70.2	71.3	85.3	86.4	87.0	85.3	80.2
	Z		91.4	43.2	46.3	56.0	72.5	78.1	88.3	85.4	83.2	78.8

CHARACTERISTICS OF THE MINE SURROUNDINGS X

1. Type of development:

- to the west of the mine, there are multi-family housing development and areas for residential and service development,
- to the east of the dump site, there are single-family and multi-family housing developments as well as residential and service development areas,
- to the north, there are multi-family residential buildings and service points,
- to the south, in the immediate vicinity of the mine, there are industrial plants: a producer of foundry and blast furnace coke, and a producer of stone wool insulation materials.

2. Estimated distance of the first building line from the mine boundary:

- westwards approx. 10 m,
- eastwards approx. 120 m,
- towards the north, approx. 20 m,
- southwards approx. 250 m.

3. Estimated height of the first building line or the number of storeys:

- from the east, west and north – 4 storeys.

4. Objects reflecting acoustic waves in the vicinity of the source and the measuring point:

- the slope of the railway embankment on the eastern side,
- on the north side, buildings of a producer of stone wool insulation materials and a producer of foundry coke.

5. Measurement points.

Noise measurements in the external environment of Mine X were carried out at 10 measuring points located in the vicinity of single- and multi-family residential buildings most exposed to mine noise. The locations of selected measurement points are shown on the situational plan in Figure 2, and their coordinates and the results of measurements carried out during the day and at night in Table 2.

Fig. 2 Location of measurement points around mine X

Table 2
Examples of noise emission measurement results within the X mine

Marking the measuring point	Geographical coordinates		Noise emission level L_{Aeq}	
	Latitude (ddd° mm’ ss.s”)	Longitude (ddd° mm’ ss.s”)	Day [dB]	Night [dB]
P1	N: 50°20'42.8"	E: 18°52'26.1"	65.4	56.3
P2	N: 50°20'47.1"	E: 18°52'34.2"	69.3	59.9
P3	N: 50°20'48.9"	E: 18°52'35.2"	67.7	58.4
P4	N: 50°20'51.9"	E: 18°52'35.1"	65.2	56.3
P5	N: 50°20'52.3"	E: 18°52'32.5"	64.3	48.0
P6	N: 50°20'53.5"	E: 18°52'35.7"	58.6	46.8
P7	N: 50°20'53.7"	E: 18°52'38.2"	56.4	45.6
P8	N: 50°20'56.4"	E: 18°52'38.3"	55.5	45.1
P9	N: 50°20'56.7"	E: 18°53'14.9"	57.9	45.1
P10	N: 50°21'00.4"	E: 18°53'09.6"	56.6	45.0
P Background	N: 50°20'54.4"	E: 18°52'29.8"	60.4	43.6
All measurement points were located above the level, the area at a height of 12 m in the case of multi-family buildings with 3 floors and 18 m in the case of multi-family buildings with a greater number of floors				

CHARACTERISTICS OF THE SURROUNDINGS OF MINE Y

1. Type of development:

- to the west of the mine, there are multi-family housing development and areas for residential and service development,
- to the east of the dump site, there are single-family and multi-family housing developments, as well as residential and service development areas,
- to the north, there is a forest area with historical objects of the Silesia Stronghold Area,
- to the south, in the immediate vicinity of the mine, there are single-family houses and residential and service buildings.

2. Estimated distance of the first building line from the mine boundary:

- westwards approx. 60 m,
- eastwards approx. 50 m,
- no buildings towards the north,
- southwards approx. 10 m.

3. Estimated height of the first building line or the number of storeys:

- on the west side – 4 floors,
- from the east and south – 2 floors.

4. Objects reflecting acoustic waves in the vicinity of the source and the measuring point:

- on the west side a slope of a railway embankment and a small strip of trees.

5. Measurement points.

Noise measurements in the external environment of Mine Y were carried out at 10 measuring points located in the vicinity of only residential and multi-family residential buildings most exposed to mine noise. The locations of selected measurement points are presented on the situational plan in Figure 3, and their coordinates and the results of measurements carried out during the day and at night in Table 3.

Fig. 3 Location of measurement points around mine Y

Table 3
Examples of noise emission measurement results within the Y mine

Marking the measuring point	Geographical coordinates		Noise emission level L_{Aeq}	
	Latitude (ddd° mm' ss.s")	Longitude (ddd° mm' ss.s")	Day [dB]	Night [dB]
P1	N: 50°14'20.0"	E: 18°51'36.4"	63.2	53.2
P2	N: 50°14'18.4"	E: 18°51'43.6"	61.3	52.1
P3	N: 50°14'18.2"	E: 18°51'44.8"	60.2	50.0
P4	N: 50°14'19.7"	E: 18°51'52.5"	59.3	48.6
P5	N: 50°14'24.9"	E: 18°51'52.3"	53.8	44.2
P6	N: 50°14'33.0"	E: 18°51'57.8"	58.4	41.8
P7	N: 50°14'33.6"	E: 18°51'58.7"	57.3	40.2
P8	N: 50°14'32.8"	E: 18°50'56.5"	54.3	44.6
P9	N: 50°14'36.3"	E: 18°50'58.6"	57.6	45.0
P10	N: 50°14'37.2"	E: 18°50'57.1"	55.0	44.6
P Background	N: 50°14'37.4"	E: 18°50'50.4"	63.2	41.2
All measurement points were situated above the ground level, at a height of 4 m in the vicinity of a residential building and 18 m in the vicinity of multi-family buildings				

CHARACTERISTICS OF THE SURROUNDINGS OF THE Z

1. Type of development:
– towards the west, there are single-family and multi-family housing developments, as well as residential and service development areas,
– to the east of the dump, there are single-family housing areas,
– there is single-family housing development to the north,
– to the south, there are single-family and multi-family housing developments, with a predominance of multi-family housing and collective housing.

2. Estimated distance of the first building line from the mine boundary:
– northwards approx. 60 m,
– eastwards approx. 10 m,
– westwards approx. 110 m,
– southbound approx. 25 m.

3. Estimated height of the first building line or the number of storeys:
– from the north and east side – 2 floors,
– from the south and west – 4 storeys.

4. Objects reflecting acoustic waves in the vicinity of the source and the measuring point:
– on the north-eastern side, these facilities are the boiler room, the gym building, as well as the cooling tower belonging to the Heat and Power Plant,
– on the eastern side, the above-level structure of the former settler, Starzykowice, with a 30-meter-high embankment,
– a 10 m high slope on the northern side,
– the slope of the railway embankment on the south side.

5. Measurement points.

Measurements of noise in the external environment of Mine X were carried out at 10 measuring points located in the vicinity of only residential and multi-family residential buildings most exposed to mine noise. The locations of selected measurement points are shown on the situational plan in Figure 4, and their coordinates and the results of measurements carried out during the day and at night in Table 4.

Fig. 4 Location of the measurement points around the Z mine

Table 4
Example results of measurements of the noise emission level within the Z mine

Marking the measuring point	Geographical coordinates		Noise emission level L_{Aeq}	
	Latitude (ddd° mm' ss.s")	Longitude (ddd° mm' ss.s")	Day [dB]	Night [dB]
P1	N: 50°04'03.2"	E: 18°33'36.5"	57.6	46.7
P2	N: 50°06'60.3"	E: 18°55'92.6"	51.1	44.4
P3	N: 50°04'00.5"	E: 18°33'22.7"	48.1	43.3
P4	N: 50°04'01.0"	E: 18°33'17.0"	45.6	42.1
P5	N: 50°04'01.3"	E: 18°33'19.4"	47.3	44.8
P6	N: 50°04'02.7"	E: 18°33'02.9"	44.7	41.8
P7	N: 50°04'06.7"	E: 18°32'54.0"	45.1	42.3
P8	N: 50°04'10.2"	E: 18°32'54.7"	46.5	44.8
P9	N: 50°04'11.5"	E: 18°32'57.0"	54.3	46.5
P10	N: 50°04'10.2"	E: 18°32'54.7"	48.6	44.6
P Background	N: 50°04'03.2"	E: 18°33'36.5"	43.5	39.2
All measurement points were located above the level of the area at a height of 4m in the vicinity of a residential building and 18m in multi-family buildings				

RESULTS OF RESEARCH

All acoustic measurements were carried out using the Sonopan DSA-50 integrating sound level meter with the serial number 545/2019 with the current calibration certificate number L3.55.2019.01; 18/02/2019 allowing measurement also in octave bands and the Sonopan KA-50 acoustic calibrator No. 108/06 with the current calibration certificate No. L3.43.2019.05; 02/11/20219. The LB-706B/LB-701 thermo hygro barometer with the serial number 657/3069 and the calibration certificate number 42424/2016 was also used to determine the meteorological conditions during the measurements; 12/02/2016 and a vane anemometer with a CHY 361 probe, serial number 080396; probe No. 081139 with calibration certificate No. 228/A/15; April 13, 2015. During the measurements, depending on the time of night and day, the average wind speed ranged from 0 to 3.1 m/s, the average temperature was from 5.5 to 15˚C, air humidity ranged from 75.5% to 78.9%, and the atmospheric pressure from 1000 to 1008 hPa.

NORMATIVE RESTRICTIONS

In accordance with the Regulation of the Minister of the Environment of 14.07.2007 on permissible noise levels in the environment (Journal of Laws 2007, No. 120, item 826), as amended (Journal of Laws 2012, item 1109), the permissible noise level, expressed equivalent sound level A, is respectively:

- for single-family housing development areas:
  - 50 dB during the daytime, from 6:00 a.m. to 10:00 p.m.,
  - 40 dB at night, from 10:00 p.m. to 6:00 a.m.,
- for residential and service and farm development areas, areas for multi-family housing and collective housing, areas in the downtown area of cities over 100,000 residents:
  - 55 dB during the daytime, from 6 a.m. to 10 p.m.,
  - 45 dB at night, from 10 p.m. to 6 a.m.

Industrial, production and storage areas are not acoustically protected areas.

When calculating the normative values, it should be remembered that for industrial noise the reference time is: T = 8 consecutive hours of the time of day, e.g., from 7 a.m. to 3 p.m. ⇒ T = 480 min = 28,800 seconds; T = 1 most unfavorable hour of the night, i.e., between 10 p.m. and 6 a.m. ⇒ T = 60 min = 3600 seconds

THE RESULTS OF NOISE MEASUREMENTS PERFORMED BY SAMPLING METHOD

Measurements of noise resulting from the operation of machines, devices and installations of the surface part of hard coal mines were made on the basis of the "Reference methodology for periodic measurements of environmental noise from installations or devices, except for impulse noise" constituting Annex 7 to the Regulation of the Minister of the Environment of October 30, 2014 on the requirements for the measurement of emission levels and measurements of the amount of water abstracted (Journal of Laws of 2014, item 1542) [29]. The measurements were performed using the sampling method (registration of elementary noise samples at the reference time T). The average noise level LA was calculated on the basis of elementary noise samples from the formula (1):

$$L_{Aśr} = 10log\left(\frac{1}{n}\sum_{k=1}^{n} 10^{0,1L_{Ak}}\right) \text{ [dB]}, \quad (1)$$

where:

n – number of samples in the measurement series,

L_{Ak} – measured sound level over time t_o (noise sample measurement result), [dB].

The noise emission level L_{Aeq} was obtained by subtracting from the average level value given by the formula (1), the acoustic background level value, according to the formula (2):

$$L_{Aek} = 10log(10^{0,1L_{Aśr}} - 10^{0,1L_{At}}) \ [dB], \quad (2)$$

where:

L_{Av} – the average sound level A for the period t_p or the average sound level for the source, [dB],

L_{At} – the average A-level of the background noise, [dB].

The noise level at the measuring point, expressed in A-weighted sound level for the reference time T ($L_{Aeq.T}$), was calculated from the formula (3):

$$L_{Aeq,T} = 10log\left(\frac{1}{T}\sum_{j=1}^{m} t_j 10^{0,1L_{Aekj}}\right) \text{ [dB]}, \quad (2)$$

where:

m – number of time slots t_p or number of sources measured,

L_{Aekj} – level of L_{Aek} for j-th time interval t_p or j-th source, [dB],

t_j – duration of the j-th time interval t_p or work time of the j-th source, [min],

T – reference time, [min].

where:

- for the time of day (6:00 a.m. to 10:00 p.m.) T = 480 minutes,
- for the time of night (10:00 p.m. to 6:00 p.m.) T = 60 minutes.

Value of $L_{Aeq,T}$ calculated in accordance with formula (3) corresponds to the value of the noise index $L_{Aeq\,D}$ and/or $L_{Aeq\,N}$. If the measuring point is located at the facade of the building, at a distance of 0.5 to 2 m from a closed or tilted window, the test result is reduced by 3 dB.

DESCRIPTION OF HOW TO DETERMINE THE MEASUREMENT UNCERTAINTY

The tests assumed the expanded uncertainty for the noise test result for the 95% confidence level (U95) it contains:

- estimation of the B-type standard uncertainty – the equipment used to measure the sound level, considering the information on the uncertainty/limit errors of the measuring instruments declared by the manufacturer, compliance with the requirements of PN-EN 61672-1 [30], calibration results, metrological requirements, impact of environmental conditions,
- estimation of the A-type standard uncertainty – based on a series of elementary measurements (noise samples).

SAMPLE CALCULATION RESULTS

Due to the length of the computational material, the article presents the measurement results of the Z mine carried out in March 2020 during the day and nighttime for an example of four measurement points (Table 5). Before taking individual measurements, the measuring instruments were calibrated. The calibration correction for measurements during the daytime was 0.1dB, and for measurements at nighttime was 0.0 dB.

Table 5

Examples of measurement results for the Z mine

Interval t_p or the source name	The measured sound level of the sample	Sample measurement time	Average A-sound level for the tp or source interval	The average background noise level	Noise emission level	Duration of the interval t_p or source runtime
	L_{Ak} [dB]	t_o [s]	$L_{Aśr}$ [dB]	L_{At} [dB]	L_{Aek} [dB]	t_j [s]
P1 General mine work (undetermined noise)	Daytime measurement results from 5:00 p.m. to 6:00 p.m.					
	58.3	300	58.6	51.4	57.6	28800
	59.1	300				
	57.9	300				
	59.2	300				
	58.2	300				
	Measurement results at nighttime from 10:00 p.m. to 11:00 p.m.					
	48.1	300	47.8	41.2	46.7	3600
	47.3	300				
	48.2	300				
	47.6	300				
	47.8	300				
P2 General mine work (undetermined noise)	Daytime measurement results from 6:00 p.m. to 7:00 p.m.					
	54.2	300	53.6	50.0	51.1	2888
	52.9	300				
	53.8	300				
	54.2	300				
	52.6	300				
	Measurement results at nighttime from 10:10 p.m.to 11:35 p.m.					
	44.2	300	45.7	40.1	44.4	3600
	42.9	300				
	43.9	300				
	44.0	300				
	42.7	300				
P3 General mine work (undetermined noise)	Daytime measurement results from 7:10 p.m. to 8:00 p.m.					
	48.7	300	49.4	43.5	48.1	28800
	50.3	300				
	49.0	300				
	49.4	300				
	49.3	300				
	Measurement results at nighttime from 00:10 to 01:00 a.m.					
	45.3	300	45.0	40.2	43.3	3600
	44.7	300				
	44.3	300				
	45.2	300				
	45.6	300				
P4 General mine work (undetermined noise)	Daytime measurement results from 8:10 p.m. to 9:00 p.m.					
	47.4	300	47.7	43.6	45.6	28800
	48.2	300				
	47.6	300				
	47.8	300				
	47.5	300				
	Measurement results at nighttime from 01:10 a.m. to 02:00 a.m.					
	42.9	300	43.9	39.2	42.1	3600
	44.4	300				
	44.1	300				
	43.6	300				
	44.0	300				

RESULTS AND DISCUSSION

Determination of the A-weighted sound level for the reference time T in terms of the noise index L_{AeqD} or L_{AeqN}, together with the measurement uncertainty (expanded uncertainty estimated for the confidence level of 95% (U95). The results are summarized in Table 6.

Table 6
Determined equivalent sound level A for reference time T. mine Z

Measurement point number	A-weighted sound level value for the reference time T. expressed as a noise index [dB]		A-weighted sound level value for the reference time T. in terms of the corrected noise index [dB]	Measurement uncertainty U_{95} [dB]	
				symbol	value
P1	L_{AeqD}	51.1	51.1	U_{95}	1.6
	L_{AeqN}	44.4	44.4	U_{95}	1.6
P2	L_{AeqD}	57.6	57.6	U_{95}	1.6
	L_{AeqN}	46.7	46.7	U_{95}	1.6
P3	L_{AeqD}	48.1	48.1	U_{95}	1.6
	L_{AeqN}	43.3	43.3	U_{95}	1.6
P4	L_{AeqD}	45.6	45.6	U_{95}	1.6
	L_{AeqN}	42.1	42.1	U_{95}	1.6

The analysis of the obtained measurement results (Table 2, Table 3, Table 4) showed that each digging emits noise to the external environment resulting from technological processes exceeding the permissible values at day and night. The highest noise level in residential buildings is found in multi-family buildings grouped around mine X. The maximum noise levels during day and nighttime here are over 14 dB. This is due to the close proximity of multi-family buildings in the vicinity of the mine boundary, but also the lack of adequate infrastructure to suppress noise emitted by mining machinery and equipment, whose equivalent sound level A, as shown by the results summarized in Table 1, often exceeds the value of 90 and 100 dB. In the X mine, losses in the external façade and broken ends in some objects can also be observed. Most of the processes also take place with open technological gates due to the continuity of production processes related to the lowering of materials necessary for production and the transport of excavated material and waste rock to the surface. In the case of mine Y, the main noise levels concern single-family housing, for which the permissible values for multi-family housing are 5 dB lower during day and night. The maximum noise level for single-family buildings located in the vicinity of up to 30 m from the border of the Y mine is 13 dB, and for multi-family buildings it is 2.6 dB. As in the case of mine X, the noise-generating technological processes in mine Y exceed the A-weighted sound levels of 90 and 100 dB. However, the Y mine is 60 years younger than the X mine, hence the structure of surface facilities is made of materials with increased acoustic insulation, which result in an average of about 20% lower emission of industrial noise to the external environment. The Z Mine is an example of a mine where much more attention is paid to reducing noisy technological processes. The shielding of the mine's surface structures and the introduction of partial soundproofing and sound-insulating casings of mining equipment mean that the noise levels in the external environment during day and night time only apply to single-family buildings and amount to about 7 dB.

CONCLUSIONS

Industrial noise, although it is a factor polluting the external environment, does not require the entrepreneur to obtain a separate administrative decision or an emission permit today. Apart from a few cases related to the need to obtain an integrated permit for the installations operated in the enterprise, the aspect of the enterprise's acoustic impact on the external environment occurs only when planning a new project on the premises of the facility related to the modernization of the existing infrastructure, expansion of the facility or construction of new facilities and installations. Measurements of noise emissions to the external environment in accordance with the applicable legal regulations are performed periodically (once every two years), considering the specificity of work of the sources by PCA-certified research laboratories. As shown by the research carried out and the measurement results obtained for residential buildings located within three mines, carrying out noise emission tests once every two years in a constantly dynamically changing environment is not an optimal solution. This is because it does not affect the reduction of noise in the enterprise, or the improvement of environmental conditions, because the preventive actions undertaken by enterprises have only an action dimension, and not a systematic and repeatable one.

Most production companies with increased noise pollution still treat noise emitted into the environment, noise at workplaces and noise of machinery and equipment separately. Meanwhile, the measurements of the sources of noise in mines X, Y, Z show that the operation of mining machinery and equipment in surface facilities of mines affects both employees and the areas adjacent to the mines. The production processes carried out by mines are correlated with each other, so the noise generated by them should be presented comprehensively through the ongoing acoustic analysis of the enterprise and the observation of changes taking place in the environment. Passive or active noise reduction modes will not bring the expected results if the entrepreneurs do not monitor the general acoustic climate of the plant and exceed the permissible noise level on an ongoing basis.

To meet the expectations of the society and thousands of employees in the field of industrial noise reduction, the employees of the Department of Safety Engineering of the Silesians University of Technology, as part of the implemented project, began work on the construction of a device for continuous noise measurement in industrial conditions, which, in cooperation with the dispatching systems of hard coal mines, will warn employees against excessive noise at the workplace (Fig. 5).

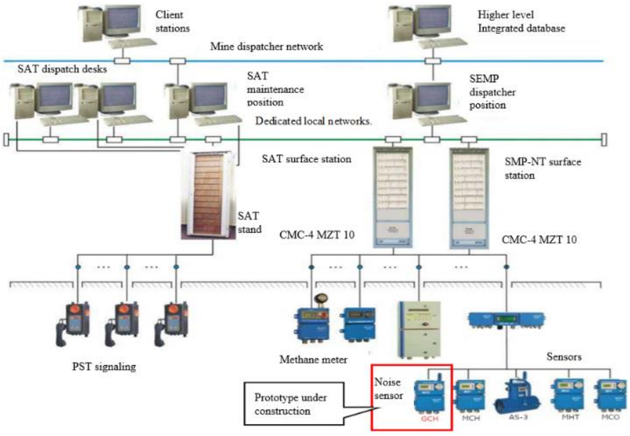

Fig. 5 Schematic diagram of continuous noise monitoring in the mine by the dispatcher's system
Source: [31].

Acoustic monitoring of technological processes will also become an element of diagnostics of mining machines and devices, allowing to assess their current situation as well as working conditions [32, 33]. The acoustic monitoring system of technological processes should also affect the ongoing and appropriate implementation of more effective preventive measures to reduce the noise level inside and outside mines.

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