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Health effects of long-term exposure to industrial dust in preparation plants of hard coal mines

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Abstract

Statistical data on occupational diseases registered by the Institute of Occupational Medicine in Łódź indicates a renewed increase in the number of pneumoconiosis in Poland in recent years, especially in the section of PKD (Polish Classification of Business Activities) – mining. Simultaneously, in 2018, because of the implementation of Directives of the European Parliament and the Council of the European Union, changes were introduced to Polish legislation in the field of protection of workers against the risk of exposure to carcinogens or mutagens related to the respirable fraction of crystalline silica formed during work. Considering this information, the members of the Department of Safety Engineering of the Silesian University of Technology attempted to assess the dust hazard and the frequency of occurrence of respiratory diseases among the employees of the preparation plant of mine X exposed to the harmful effects of industrial dust produced in the work process. The following methods were used as part of the research: individual dosimetry, infrared spectrometry, directional interview, diagnostic tests, and spirometry. The obtained results made it possible to identify workstations with the highest exposure to the harmful effects of industrial dust and to recognize the impact of this action in the form of pathological changes in the respiratory system in 18.4% of the miners surveyed.

Introduction

The report of the Central Register of Occupational Diseases (Świątkowska & Hanke, 2021), published in 2021 by the Institute of Occupational Medicine, shows that in 2020 1850 new cases of occupational diseases were recorded in Poland. The most frequently diagnosed cases of occupational diseases in this period were infectious or parasitic diseases or their sequelae. In total, 505 such cases were recorded, which constitutes 27.3% of occupational diseases diagnosed in 2020 in Poland. Interestingly, this group also included 38 cases of COVID-19 for the first time, which had not been recorded before. The second group of diseases in terms of the number of reported cases were pneumoconiosis – 490 cases (26.5%, occupational pathologies), which since 2018 (392 cases) have recorded a steady increase of over 25%. Among the diagnosed cases of pneumoconiosis in Poland in 2018–2020, pneumoconiosis of miners of mines dominates – 774 cases (58.0% in this group), asbestosis – 279 cases (20.9%), and silicosis – 239 cases (17.9%). These three disease entities account for 96.8% of all pneumonia recorded in the last three years in Poland. The highest incidence per 100 thousand employed in 2020 was recorded in mining (276.3 cases), education (23.3 cases), agriculture and forestry (18.0 cases), industrial processing (16.9 cases), as well as healthcare and assistance social (13.0 cases). Occupational incidence rates among mining workers have remained at a very high level for years (2018 – 184.5 cases and 2019 – 216.4), almost ten times higher than in the next group of socio-economic activities, i.e., education (9.6), and 18 times higher than the average in Poland. It is disturbing that despite the decline in employment in recent years in the mining industry by nearly 3.5 thousand employees (2018 – 91,014 employees and 2020 – 87,566), the incidence of pneumoconiosis in the same period increased by 49.8% (WUG, 2021).

Among the harmfulness and nuisances of the work environment, recognized as the main causative factor of occupational diseases according to the Institute of Occupational Medicine in Łódź, industrial dust is also mentioned the most frequently (36.7% of occupational diseases), including dust containing asbestos and hard coal and lignite dust containing free silica. In addition to various types of pneumoconiosis (N = 490 for 2020), industrial dust was indicated as a factor that contributes to the development of pleural diseases, asthma, allergic rhinitis, and extrinsic allergic alveolitis.

Exposure to industrial dust is also the most common cause of malignant neoplasms, which is considered an occupational disease. Among 193 cancers diagnosed in 2018–2020, 164 cases (85%) were caused by asbestos dust, and 36 (18.7%) by dust containing free crystalline silica. These types of dust are responsible for 106 confirmed cases of lung cancer and all cases of mesothelioma (67). Although the total number of occupational diseases in Poland has decreased in recent years, the incidence of pneumoconiosis is growing. The leader in this respect is traditionally the Śląskie Voivodeship, where over 50% of all cases of pneumoconiosis in Poland are recorded each year. This regularity is related to the structure of the industry in the Śląskie Voivodeship and the highest percentage of people employed in the mining industry in the country.

Therefore, the increase in the number of cases of this disease is worrying, especially as they are often chronic diseases that significantly impact health, and their development may take years. Hence, early detection of disease symptoms and prompt initiation of treatment have the greatest impact on the course of the disease and its possible consequences. Too late of a diagnosis of a patient's ailments may have dire and irreversible consequences for saving health. That is why such an important element in the fight against this group of occupational diseases is to take appropriate preventive measures to reduce the presence of dust at the workplace and to cover employees at risk of industrial dust with the appropriate medical prophylaxis, especially in mines and mining plants extracting hard coal, where these diseases are the most numerous.

Employees of the Department of Safety Engineering at the Silesian University of Technology, together with students at the Pomeranian Medical University in Szczecin and specialists in the field of pulmonology, attempted to assess the actual working conditions in the zone of harmful dust exposure in the preparation departments of mine X to meet the expectations mentioned above. These studies were combined with the voluntary medical examinations of miners. The innovation of this research method allows for more precise verification of the causes and health effects of occupational pneumoconiosis, which so far was most often diagnosed based on disease symptoms in the advanced stage without examining the causes and properties of the dust that caused it.

Literature review

Despite many international efforts and actions taken (López-Campos, Soler-Cataluñaand & Marc Miravitlles, 2019) to limit the exposure of hard coal mine workers to contact with harmful dust generated in the mining process (Liu & Liu, 2020), tens of thousands of miners around the world are still exposed to its harmful effects (Laney & Weissman, 2014). The result of this exposure is pneumoconiosis (Barber & Fishwick, 2016), common among miners with acute-fibrotic and chronic-insufficiency (Han et al., 2018), which for years has been the subject of research and scientific publications by many researchers from Columbia (Torres Rey et al., 2015), the Czech Republic (Tomášková et al., 2017), Poland (Brodny & Tutak, 2018), Asia (Perret et al., 2017), Australia (Zosky et al., 2016), the United States of America (Hall et al., 2019), and other industrialized countries of the world.

To reduce the risks in mining excavations of hard coal mines, in addition to personal protective equipment provided to employees exposed to dust-generating processes, technical solutions are also used. This limits the amount of dust generated or deprives it of its volatile properties. Among the most effective technological solutions that should be mentioned are the following:

- ventilation systems (Bałaga et al., 2015; Ji et al., 2016);
- sprinkling systems mounted on the heads of mining machines (Bałaga et al., 2016; Lutyński, 2021);
- water curtains installed in mining excavations (Bałaga, 2019; Peng et al., 2022);
- dedusting devices (Kuczera & Ptaszyński, 2019; Xu & Wang, 2021);
- rock mass irrigation (Zhang et al., 2022; Liao et al., 2021).

Taking care of the health and life of employees is one of the basic obligations of the employer, resulting directly from the Labor Code (ISAP, 1974) and other industry legal regulations. Actions to effectively prevent occupational diseases can be divided into three categories.

The first one is primary prevention, i.e., care for the work environment, occupational health and safety (Tobór-Osadnik, Wyganowska & Manowska, 2017), and other activities aimed at creating safe working conditions. This purpose is served by properly conducted environmental measurements of dust at the workplace and occupational risk assessment (Mocek, 2002), which enable effective preventive measures to reduce the occurrence of dust hazards (Krzemień & Mocek, 1999; Korban, 2019). The second is promoting knowledge about work safety (Korban, 2015), persuading employees to change their behavior, and shaping the desired attitudes in employees (Wyganowska, 2019). All of which result in a real improvement in working conditions and conscious action to protect one's own health (Biały, 2012, p. 17).

The third should be appropriate medical prophylaxis, enabling ongoing monitoring (Ergün et al., 2017) of the health of the workers most exposed to harmful dust, preventing the diseases or detecting it as early as possible (Zhang, 2021). Therefore, in addition to the periodic environmental measurements required by law, employers should also provide employees with access to medical care allowing for regular and more frequent health checks (Yang et al., 2017) and, thus, fulfilling the provisions of article 101 Regulation of the Minister of Labor and Social Policy of September 26, 1997 on general provisions on health and safety at work and article 222 of the Labor Code.

Methodology

Research on the health effects of long-term exposure to industrial dust in the selected preparation plant of mine X was performed by employees of the Department of Safety Engineering of the Silesian University of Technology, in cooperation with employees of the Central Laboratory for Work Environment Research "Stanisław Bielaszka" in Jastrzębie Zdrój and physicians in the field of pulmonology. As part of the research, in accordance with the regulations in force in Poland (ISAP, 1997; 2011; 2018), the following were carried out:

1) Measurements of dust concentration in the inhalable and respirable fractions at the workplace.
2) Measurements of chemical substances concentration at workplaces.
3) Prophylactic diagnostic tests of the respiratory system of employees of selected preparation plants.

To determine the concentration of dust from the inhalable and respirable fractions at the workplace, samples taken at the workplace were used based on the following:

- PN-Z-04008-7:2002 *Air purity protection – Sampling. Principles of air sampling in the work environment and interpretation of results*.
- PN-G-04035:2002 + Az1:2005 *Air purity protection in underground mining plants. Measurement of dust concentration in the air and determination of the content of free crystalline silica in the dust*.

For collecting samples of harmful substances (dust), the individual dosimetry method was employed using individual pumps, which enable the collection of air samples in the employee's breathing zone continuously for a period of at least 75% of the duration of the working shift. The tests of the respirable fraction and inhaled dust were based on the following standards:

- PN-91/Z-04030.06 *Determination of respirable dust at workplaces using the filtration-weighing method*.
- PN-91/Z-04030.05 *Determination of total dust at workstations using the filtration-weighing method*.

The basis for determining the concentration of crystalline silica was the method of infrared spectrometry (Maciejewska, 2012).

Before starting the measurements, an on-site inspection was made and information was collected on the following:

- location and naming of the workplace,
- type and course of technological processes,

- types of machines, devices, and activities performed,
- harmful factors specific to given technological processes,
- time of exposure to factors harmful to health (i.e., exposure time).

For the measuring equipment, individual aspirators type 224-44MTX by SKC were used to take air samples at workplaces, which are checked each time before and after the measurement with a rotameter type ROS-06 with the serial number 079901, containing a calibration certificate issued by the Regional Office of Measures (OUM) in Poznań accredited in PCA (No. AP 084). The filters used for measurements were dried to a constant mass in a desiccator and then weighed on a RADWAG AS60/220.R2 balance, serial number 508222, with a verification certificate issued by "TOPS" S.C. Mass Measurement Laboratory accredited by PCA (No. AP 093).

Each filter was assigned appropriate frames (inhalable fraction) and cyclones (respirable fraction). To determine the concentration of chemical substances at workplaces, tests and measurements were performed based on: PN-Z-04008-7:2002 and PN-Z-04008-7:2002/Azl December 2004 *Principles of air sampling in work environment and interpretation of results*.

Based on the determined concentration values in the samples of dust (and/or chemicals), the average weight concentration was determined – formulas (1) and (2) – and the EC exposure indicators were calculated for the entire work shift – formula (3). For samples taken by individual dosimetry on the basis of formula (1), we find:

$$C_w = \frac{C_1 \cdot t_1 + C_2 \cdot t_2 + C_3 \cdot t_3 + \cdots + C_n \cdot t_n}{t_1 + t_2 + t_3 + \cdots + t_n} \tag{1}$$

where C_1, C_2, ... C_n represent the concentrations obtained as a result of the determination of individual samples [mg/m^3], t_i is the time of taking individual samples [min], and n is the number of samples.

For samples taken by the stationary method, based on formulas (2) and (3), it is determined that:

$$\overline{X}_{gw} = \frac{\overline{X}_{g1} \cdot t_1 + \overline{X}_{g2} \cdot t_2 + \overline{X}_{g3} \cdot t_3 + \cdots + \overline{X}_{gk} \cdot t_k}{t_1 + t_2 + t_3 + \cdots + t_k} \tag{2}$$

where X_{g1}, X_{g2}, ... X_{gk} denote the concentrations obtained as a result of the determination of individual samples [mg/m^3], t_1, t_2, t_3, ... t_k is the duration of individual measuring periods in minutes, and k is the number of measuring periods. In addition:

$$W_E = C_W \cdot \frac{T_e}{T_o} \quad \text{or} \quad W_E = \overline{X}_{gw} \cdot \frac{T_e}{T_o} \tag{3}$$

where C_W, X_{gw} signifies the weighted average concentration of a specific dust/chemical type, expressed in [mg/m^3], T_e is the exposure time per shift, expressed in minutes, T_o is the reference time for an 8-hour run time, i.e., 480 minutes, and W_E is the exposure index.

The working conditions are considered safe if the calculated exposure index does not exceed the value of the maximum permissible concentration (NDS) for a given substance, and the exposure index (WN) is less than or equal to 1 in the following formula:

$$W_N = \frac{W_E}{\text{NDS}} \leq 1 \tag{4}$$

where W_N represents the exposure factor, W_E is the exposure index for total or respirable dust or chemical, expressed in [mg/m^3], and NDS is the maximum permissible concentration for total or respirable dust or a chemical substance, expressed in [mg/m^3].

For the collection of samples of harmful substances (chemical agents), the individual dosimetry method was used, using individual pumps that allow for the taking of air samples in the breathing zone of the employee, continuously for a period of at least 75% of the duration of the working shift. For the measuring equipment, individual aspirators type 224-44MTX by SKC were used to take air samples for testing the concentration of chemical substances at workplaces, which are checked each time before and after the measurement with a rotameter type ROS-06 with the serial number 079901, having a calibration certificate issued by OUM in Poznań accredited in PCA (No. AP 084). The filters used for measurements were dried to a constant mass in a desiccator and then weighed on a RADWAG AS60/220.R2 balance, serial number 508222, with a calibration and calibration certificate issued by "TOPS" S.C. Mass Measuring Laboratory accredited by PCA (No. AP 093).

Chemical analysis was performed with the following equipment:

- crystalline silica: Perkin Elmer FT-IR Spectrum TWO spectrophotometer, serial number 97389 – polystyrene foil calibration certificate issued by the Central Office of Measures – via the method of infrared absorption spectrophotometry.

Prophylactic diagnostic tests of employees of selected preparation plants were performed based on a medical interview with the patient, physical examinations, and spirometry.

Results and discussion

One of the basic organizational structures of each deep coal mine is the preparation work plants, whose main task is to make the coal seam or deposit available by dividing it along and across selected fields by means of preparatory excavations, which include sidewalks, ramps, tops, slopes, longwall cuts, etc. Preparatory workings, also known as corridor workings, can be performed on one mining level at a slight slope, and then they most often serve as longwall workings for the designed service walls. They can also be bored as sloping headings connecting two or more points at different levels of the mine. Preparation plants also drill other underground facilities such as chambers, depots, warehouses, settling tanks, etc. Depending on the system of works used, preparatory workings are drilled in coal, stone, or a combination of these geological structures using mining machines or explosives. Due to the limited spatial dimensions of the preparatory workings (height 3.0–5.5 m, width 3.5–8.0 m, long runs reaching even several kilometers) and the limited ventilation possibilities, the technological processes used in their implementation cause immense dustiness in the air. In the latter, apart from ground particles of coal and stone, there may be other minerals including free crystalline silica (Figure 1).

As part of the research, air dustiness was measured at three preparation plants: GRP-1 – carrying out works in a drilled mine face with the use of an AM-50 roadheader, GRP-2 – drilling a rock surface with explosives, and GRP-3 – leading coal with the AM-75 combine. Suction duct ventilation was used in all the excavated workings.

The results of dust measurements at selected positions of the preparatory works departments of mine X are presented in Table 1; the chemical substances are given in Table 2. The following numbers were assigned to individual workstations: roadheader operator – 1, roadheader operator's assistant – 2, miner-builder – 3, miner in transport – 4, conveyor service – 5, face miner – 6, blast miner – 7, and drill – 8.

The circumstances of the sampling during the 450-minute exposure period included activities performed by employees of the preparation plant, such as:

- ingress and exit through the shaft to the mine, riding the railway to the area of the longwall, and access and return from the workplace,
- preparatory works,
- operation of roadheader, conveyors, and face devices,
- mining with a roadheader and mining with explosives,
- development of the pavement housing elements and the liner,
- drilling blast holes and control holes,
- transport of materials to the longwall, lengthening of the lute, and reconstruction of mine face devices,
- technological breaks.

The conducted research shows that all workplaces in the examined preparation plants are endangered by excessive exposure to dust and harmful substances.

Figure 1. Dustiness during mine face works with the use of the AM-50 roadheader and explosives

Table 1. Results of the measurements of air dustiness with hard coal dust at individual positions of preparation plants using the dosimetric method

Ward	Position	Dust concentration range in the fraction [mg/m³]		Indicator W_E [mg/m³]		NDS		Indicator W_N (times of NDS)	
		Inhaled	Respirabled	Inhaled	Respirabled	Inhaled	Respirabled	Inhaled	Resp.
GRP-1	1	0.71–48.68	0.35–15.12	46.33	14.63	10	2	4.6	7.3
	2	0.68–46.13	0.30–14.65	44.18	14.14	10	2	4.4	7.1
	3	0.44–39.48	0.15–11.31	33.52	10.45	10	2	3.4	5.2
	4	0.25–24.14	0.07–8.30	42.30	12.80	10	2	4.2	6.4
	5	0.32–34.20	0.13–10.38	30.17	8.46	10	2	3.0	4.2
GRP-2	1	0.51–35.10	0.26–9.11	33.82	10.20	10	2	3.4	5.1
	2	0.48–33.22	0.20–9.64	31.36	9.34	10	2	3.1	4.7
	3	0.28–26.46	0.11–7.30	24.29	7.28	10	2	2.4	3.6
	4	0.09–21.13	0.07–6.35	19.21	6.13	10	2	1.9	3.1
	5	0.23–31.77	0.15–8.38	31.20	8.96	10	2	3.1	4.5
	6	0.12–26.30	0.04–6.33	24.78	7.47	10	2	2.5	3.7
GRP-3	3	0.10–7.91	0.02–1.46	7.36	1.36	10	2	0.7	0.7
	4	0.08–7.83	0.01–1.23	7.23	1.12	10	2	0.7	0.6
	5	0.24–12.6	0.04–2.02	11.3	1.98	10	2	1.1	1.0
	6	0.09–7.42	0.01–1.11	6.84	0.93	10	2	0.7	0.5
	7	0.31–8.96	0.03–1.43	8.20	1.17	10	2	0.8	0.6
	8	0.26–7.38	0.02–1.26	6.65	1.10	10	2	0.7	0.6

Table 2. Measurement results of the chemical substance of crystalline silica at individual stations of the preparation plants using the dosimetric method

Ward	Position	Concentration range of crystalline silica in the respirable fraction [mg/m³]	Indicator W_E [mg/m³]	NDS of respirable fraction	Indicator W_N (times of NDS)
GRP-1	1	0.037–0.335	0.312	0.1	3.1
	2	0.034–0.316	0.296	0.1	3.0
	3	0.023–0.285	0.262	0.1	2.6
	4	0.040–0.348	0.319	0.1	3.2
	5	0.026–0.289	0.243	0.1	2.4
GRP-2	1	0.046–0.621	0.600	0.1	6.0
	2	0.038–0.610	0.592	0.1	5.9
	3	0.026–0.555	0.514	0.1	5.1
	4	0.009–0.214	0.196	0.1	2.0
	5	0.028–0.582	0.563	0.1	5.6
	6	0.025–0.430	0.403	0.1	4.0
GRP-3	3	0.058–0.918	0.890	0.1	8.9
	4	0.031–0.466	0.421	0.1	4.2
	5	0.076–1.215	1.200	0.1	12.0
	6	0.047–0.860	0.842	0.1	8.4
	7	0.060–1.110	0.983	0.1	9.8
	8	0.067–1.126	1.089	0.1	10.9

The highest concentrations of dust are found at the roadheader operator and roadheader operator's assistant's stands in longwall excavated with a roadheader, and at the drill and blaster's stands in coal faces prepared with the use of explosives. The presence of crystalline silica in the air inhaled by miners, even in the coal face, undoubtedly has a decisive impact on the state of danger for the working mining crews, where its content should theoretically be negligible.

It turns out that the fresh air supplied to the coal face already contains significant amounts of silica, which make it exceed the current normative values for this chemical substance at the workplace. Therefore, the frequency of environmental measurements

Table 3. Frequency of measurements depending on the concentrations of harmful factors found

Workplace number			Indicator W_N (times of NDS)	Research frequency
GRP-1	GRP-2	GRP-3		
Name of the harmful factor – coal (hard coal and lignite)				
			NDS < 0.1	*
			0.1 < W_N < 0.5 NDS	At least every two years
1,2,3,4,5	1,2,3,4,5,6	3,4,5,3,7,8	W_N > 0.5 NDS	At least once a year
Name of the harmful substance – crystalline silica (quartz and cristobalite)				
			0.1 < W_N < 0.5 NDS	At least once every six months (carcinogenic or mutagenic agents are present)
1,2,3,4,5	1,2,3,4,5,6	3,4,5,3,7,8	W_N > 0.5 NDS	At least once every three months (carcinogenic or mutagenic agents are present)

* – according to § 7. Regulation of the Minister of Health of 02.02.2011 on tests and measurements of agents harmful to health in the work environment (Journal of Laws No. 33 of 2011), as amended.

at the mine is increasing (Table 3) and, consequently, the employer should take additional preventive measures to improve working conditions and monitor the health of people exposed to carcinogens.

To supplement the collected results of measurement tests, anonymous diagnostic tests of the respiratory system were also performed among the 87 employees of the preparation plants (GRP-1, GRP-2, and GRP-3) of mine X. Their aim was to assess the frequency of respiratory disorders among the examined miners. The scope of diagnostic tests included:

a) medical interview with the patient – the purpose of which was to become acquainted with: the employee's identification data; his individual characteristics such as age, height, and body weight; health ailments; illnesses; family health burdens, lifestyle, addictions, and working conditions. In this study, the CAT – COPD Assessment Test (Farnik et al., 2019) was used to assess the patient's current ailments, which identified the patient's symptoms such as cough, sputum retention, tightness in the chest, daily activity at home and outside, dyspnea, anxiety and uncertainty, sleep disturbances, and energy to act (Table 4).

b) physical examination – the purpose of which was to conduct a general assessment of the health and appearance of the examined employee using the

Table 4. Results of the CAT test of the employees of the preparation plant of mine X

Occurring symptoms	Age of respondents							
	≤ 20	21–25	26–30	31–35	36–40	41–45	46–50	> 50
	Total number of respondents (responders (smokers))							
	2 (1)	7 (4)	10 (4)	14 (10)	23 (18)	16 (11)	9 (4)	6 (3)
	Number of respondents (average CAT points)							
Cough	–	2 (3.0)	2 (3.5)	–	11 (3.4)	9 (3.7)	6 (3.5)	5 (4.2)
Residual sputum	2 (3.0)	2 (3.0)	10 (3.0)	14 (3.3)	23 (3.5)	16 (3.5)	9 (4.0)	6 (4.5)
Tightness in chest	–	–	–	–	2 (3.0)	3 (2.7)	4 (3.5)	2 (3.5)
Shortness of breath	–	–	–	–	2 (3.5)	3 (3.3)	4 (3.8)	2 (3.5)
Tiredness	–	–	2 (3.5)	–	5 (3.0)	8 (3.4)	4 (3.5)	5 (4.0)
Anxiety and insecurity	–	–	–	–	–	2 (3.0)	2 (3.0)	2 (3.0)
Sleep disturbance	–	–	–	–	–	2 (3.5)	3 (3.7)	2 (3.5)
Lack of energy	–	–	1 (3.0)	–	5 (3.6)	3 (3.6)	6 (3.3)	2 (3.5)
CAT result	< 10	< 10	13	< 10	20	26.7	27.3	29.7

Interpretation of CAT results
1. 5 points – Upper limit of normal for healthy, non-smokers.
2. < 10 points – Little impact of the disease on life. Most good days. Fatigue symptoms.
3. 10–20 points – Average impact of the disease on life. Appearing shortness of breath, cough, 1–2 exacerbations a year.
4. 21–30 points – Big impact on life. If you are ill, you are unable to do most activities.
5. > 30 points – Very big impact on life. Difficult to perform basic activities.

senses of sight, hearing, and touch. This consisted of the following:
- viewing: including the patient's skin and its discoloration, the shape and appearance of the chest in terms of its structure, and the shape of the fingers of the hands;
- assessment of breathing: the proportion of inhalations and exhalations, breathing paths, chest mobility, number of breaths per minute, and respiratory disorders;
- palpation: assessing symmetry of chest respiratory movements, determining local rib pain, and assessing vocal tremor and the presence of air in the subcutaneous tissue;
- chest percussion: determine the size and mobility of the lungs, recognize fluid or air in the pleural cavity, or airlessness of the lung parenchyma;
- auscultation: enabling the detection of respiratory anomalies in the form of bronchial and pulmonary respiratory sounds, crackles, and wheezes (Table 5).

c) spirometric tests, the purpose of which was to determine the capacity and volume of the lungs of the studied workers and the airflow that occurs during various phases of the respiratory cycle. The tests were performed with the Lungtest mobile spirometer by MES, in accordance with the criteria of correctness and repeatability of basic spirometry tests according to the recommendations of the ATS – American Thoracic Society (Boros, Mejza & Gomółka, 2019). For the correctness of the tests, the apparatus was calibrated before each measurement. The employee's personal characteristics – such as age, sex, height, and body weight – were entered into the memory of the measuring device (spirometer). The examination was performed in a sitting position with the clip on the nose. The attempt to draw air into the lungs and blow air into the spirometer was repeated three times and was considered reliable if the obtained results were similar. Airway obstruction was determined in accordance with the recommendations of the GOLD report for COPD (Graham et al., 2019) based on the finding of airflow limitation during exhalation based on the obtained FEV1/FVC and FEV1 values (Table 6).

The diagnostic tests were performed based on the interviews, and the CAT test showed that over 12.6% of the surveyed miners of the preparation plants of mine X experience disturbing respiratory ailments, which clearly intensify after the age of 40 and, on average, after 17 years of continuous exposure to dust. Increased symptoms were diagnosed in roadheader operators and workers transporting broken coal from longwall, even though 56% of workers with symptoms of respiratory system disorders have never smoked cigarettes or are not exposed to industrial dust outside the mine. Minor ailments manifested by residual sputum and cough are experienced by many respondents who everyday attempt

Table 5. Results of the physical examination of the employees of the preparation plants of mine X

Identified symptoms	Age and number of respondents							
	≤ 20	21–25	26–30	31–35	36–40	41–45	46–50	> 50
	2	7	10	14	23	16	9	6
	Number tested with symptoms							
Skin changes	–	–	–	–	–	–	2	1
Chest deformity	–	–	–	–	–	1	1	1
Clubbed fingers	–	–	–	–	1	–	1	2
Shortness of breath, apnea	–	–	–	–	2	3	5	3
Prolonged exhalation	–	–	2	–	–	–	1	1
One-sided weakening of chest movements	–	–	–	–	1	2	3	2
Decrease in the number of breaths	–	–	–	–	–	2	4	2
Breathing disorders	–	–	–	1	2	2	5	3
Lowering the lungs	–	–	–	–	–	2	2	1
A dull percussion noise	–	–	–	–	–	1	2	1
A tympanic percussion noise	–	–	–	–	–	–	2	1
Voice tremor	–	–	–	–	1	1	2	2
Bronchial or pulmonary respiratory sounds	–	2	1	3	11	6	5	4
Wheezing	–	–	–	1	3	2	3	2
Crackles	1	1	4	7	10	3	2	2
Pleural friction rub	–	–	–	–	–	–	1	2

Table 6. Degree of lung function impairment in the spirometric test of employees of preparation plants of mine X

Degree of obstruction	Eligibility criteria according to FEV1	Age and number of respondents							
		≤ 20	21–25	26–30	31–35	36–40	41–45	46–50	> 50
		2	7	10	14	23	16	9	6
		Number tested with symptoms							
Slight	> 80%	–	1	1	1	1	1	1	1
Moderate	50–80%	–	–	–	–	1	2	2	1
Severe	30–50%	–	–	–	–	–	–	1	2
Very severe	< 30%	–	–	–	–	–	–	–	–

to remove impurities entering the respiratory system during work. The obtained results of the interview are also confirmed by physical examinations, especially auscultatory ones, which in almost half of the respondents (48.3%) show crackles, wheezes, whirring indications of narrowing of the airways inside or behind the chest, and the presence of secretions in the respiratory tract.

Interestingly, these states are observed not only in the elderly, but also in young workers between 20–30 years of age employed (especially in longwalls). Unfortunately, among the surveyed employees, there may be cases of atelectasis, emphysema, and reduced aeration of lung tissue, as evidenced by dull and tympanic percussion noise (7% of respondents). The research also shows the possibility of neoplastic changes in 4.6% of the respondents, manifested by pleural friction and clubbed fingers, which may indicate neoplastic fibrous lesions of the lung tissue. This observation was also confirmed by spirometric tests, which in 3.5% of respondents showed a severe degree of respiratory obstruction below 35%. In general, the features of respiratory obstruction were diagnosed in 16 people, i.e., 18.4% of the respondents. This is a significant result, especially when only two surveyed employees of the preparation plants of mine X were under the supervision of a pulmonologist; the rest were unaware of their ailments. Their preventive examinations in the diagnosis of respiratory diseases were mostly limited to a chest X-ray performed every few years. All persons diagnosed with the features of respiratory obstruction as part of the research conducted by the Department of Safety Engineering in mine X were sent for further diagnostic tests.

The conducted research is consistent with the results obtained by other researchers from Poland (Boros et al., 2022) and from abroad (Gandhi et al., 2021), who also indicated the need to extend diagnostic tests to people exposed to the harmful effects of dust (Tinkelman et al., 2007).

Conclusions

The research concept proposed by the authors, which combined the assessment of the actual working conditions in the zone of harmful dust impact with simultaneous diagnostic tests of miners exposed to them, brought measurable benefits that include the recognition of the scale of the threat. This manifested not only in the scope of exceeding the normative values at individual workplaces, but also in recognizing various diseases among miners. The obtained results indicate the need to continue research among employees of other departments of mine X, where the risk of harmful dust is also high, and to continue searching for scientific and technical solutions limiting the scale of the threat.

As shown by the environmental and medical research carried out among the employees of the preparatory departments of mine X, the current personal protective equipment – i.e., disposable filtering half-masks and collective protection measures, dust removal devices, sprinkler systems, and water curtains used in mining – are not able to completely eliminate the disease risk among employees, despite the advancement of knowledge and new technical solutions. This problem is particularly visible in the case of dust that contains free crystalline silica; therefore, most European countries have limited the limit values for respirable silica to values not exceeding 0.1 mg/m^3. In Poland, these changes were made as a result of the implementation into Polish law of Directive (EU) 2017/2398 of the European Parliament and of the Council of 12 December 2017 amending Directive 2004/37/EC on the protection of workers against the risks related to exposure to carcinogens or mutagens at work (EUR-Lex, 2017) and extending the provisions of the Regulation of the Minister of Health on chemical substances, their mixtures, agents, or technological processes with carcinogenic or mutagenic effects in the work environment to include “work related to exposure to crystalline silica – a respirable fraction generated during work" (ISAP, 2020). The introduced provision imposes on employers and doctors, who provide preventive health care for employees working in conditions of exposure to harmful dust, additional obligations consisting not only in increasing environmental measurements for air dustiness but also extending medical prophylaxis.

The conducted research and the obtained results also indicate the need to extend the medical prophylaxis among mine workers with additional tests, including spirometry, full-size chest image, capillary blood gas tests, peripheral blood counts or low-dose, and high-resolution computed tomography allowing for lung cancer screening. Such a conclusion is supported not only by the growing statistics of the incidence of pneumoconiosis in Poland, but also by new cases of pulmonary lesions identified during the research performed on the employees of the preparation departments of mine X who, according to the conducted medical interviews, are often unaware of their own ailments and underestimated disease symptoms.

An important goal of people responsible for the safety of employees in mines should also be to increase the work safety culture and the gradual replacement of the disposable FS-0/30V and FS-58V A filtering half masks, which become wet quickly in underground conditions, with reusable silicone half-masks containing filters such as SECURA DUST. Only a systematic approach to the issue of hazardous dust harmful to health, not only in mining, can limit the drama of many people exposed to numerous years of excessive exposure to industrial dust and reduce the upward trend in the incidence of occupational pneumoconiosis.

References

1. Bałaga, D. (2019) Intelligent spraying installation for dust control in mine workings. *IOP Conference Series: Materials Science and Engineering* 679, 012019.
2. Bałaga, D., Jedziniak, M., Kalita, M., Siegmund, M. & Szkudlarek, Z. (2015) Methods and means of combating dust and methane hazards in coal mining. *Maszyny Górnicze* 3, pp. 68–81 (in Polish).
3. Bałaga, D., Siegmund, M., Prostański, D. & Kalita, M. (2016) Innovative spraying system for longwall workings. *Maszyny Górnicze* 3, pp. 14–22 (in Polish).
4. Barber, C. & Fishwick, D. (2016) Pneumoconiosis. *Medicine* 44 (6), pp. 355–358.
5. Biały, W. (2012) Environmental working conditions versus occupational diseases in the hard coal mining branch. *Scientific Journals Maritime University of Szczecin, Zeszyty Naukowe Akademia Morska w Szczecinie* 31(103), pp. 37–44.
6. Boros, P., Mejza, F. & Gomółka, P. (2019) Performing spirometry according to the standards of the American Thoracic Society and the European Respiratory Society 2019. *Practical Medicine* 6, pp. 48–55.
7. Boros, P.W., Maciejewski, A., Nowicki, M.M. & Wesołowski, S. (2022) Comparability of portable and desktop spirometry: a randomized, parallel assignment, open-label clinical trial. *Advances in Respiratory Medicine* 90(1), pp. 60–67.
8. Brodny, J. & Tutak, M. (2018) Exposure to harmful dusts on fully powered longwall coal mines in Poland. *International Journal of Environmental Research and Public Health* 15(9), 1846.
9. Ergün, R., Ergün, D., Evcik, E. & Ergan, B. (2017) Evaluation of dental technician's pneumoconiosis using chest X-ray and HRCT: Correlation between radiological and functional findings. *Turkish Journal of Medical Sciences* 47(1), pp. 252–259.
10. EUR-LEX (2017) Directive (EU) 2017/2398 of the European Parliament and of the Council of 12 December 2017 amending Directive 2004/37 / EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work. *Journal of Laws UE* L 345 of 27/12/2017. Document 32017L2398.
11. Farnik, M., Brożek, G., Czajkowska-Malinowska, M., Krenke, R., Kania, A., Trzaska-Sobczak, M., Połtyn, B., Miszczuk, M., Celejewska-Wójcik, N., Kuziemski, K. & Barczyk, A. (2019) Validation of Polish language version of CAT questionnaire. *Polish Archives of Internal Medicine* 129, 9, pp. 605–611.
12. Gandhi, S.A., Cohen, R.A., Blanc, P.D. & Go, L.H.T. (2021) Early radiographic pneumoconiosis is associated with impaired exercise gas exchange among coal miners with normal resting spirometry. *American Journal of Industrial Medicine* 64(6), pp. 453–461.
13. Graham, B.L., Steenbruggen, I., Barjaktarevic, I.Z., Cooper, B.G., Hall, G.L., Hallstrand, T.S., Kaminsky, D.A., McCarthy, K., McCormack, M.C., Miller, M.R., Oropez, C.E., Rosenfeld, M., Stanojevic, S., Swanney, M.P. & Thompson, B.R. (2019) American Thoracic Society and the European Respiratory Society Standardization of spirometry 2019 update an official American Thoracic Society and European Respiratory Society technical statement. *American Journal of Respiratory and Critical Care Medicine* 200(8), pp. E70–E88.
14. Hall, N.B., Blackley, D.J., Halldin, C.N. & Laney, A.S. (2019) Current review of pneumoconiosis among US coal miners. *Current Environmental Health Reports* 6(3), pp. 137–147.
15. Han, S., Chen, H., Harvey, M.A., Stemn, E. & Cliff, D. (2018) Focusing on coal workers' lung diseases: A comparative analysis of China, Australia, and the United States. *International Journal of Environmental Research and Public Health* 15(11), 2565.
16. ISAP (1974) Act of June 26, 1974 – Labor Code (Journal of Laws of 2018, items 917, 1000 and 1076). *Polish Interactive System of Legal Acts* [Online] <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180000917> [Accessed: May 01, 2022].
17. ISAP (1997) Regulation of the Minister of Labor and Social Policy of September 26, 1997 on general provisions on health and safety at work. (Journal of Laws of 1997, No. 129, item 844). *Polish Interactive System of Legal Acts.* [Online] <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu19971290844> [Accessed: May 01, 2022].

18. ISAP (2011) *Regulation of the Minister of Health of February 2, 2011 on the law of research and measurement of factors harmful to health in the work environment*. Journal of Laws 2011 No. 33 item 166, as amended. Available from: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20110330166 [Accessed: May 01, 2022].
19. ISAP (2018) *Regulation of the Minister of Family, Labor and Social Policy of June 12, 2018. on the maximum allowable concentrations and intensities of factors harmful to health in the work environment*. Journal of Laws 2018 item 1286, as amended. Available from: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180001286 [Accessed: May 01, 2022].
20. ISAP (2020) *Regulation of the Minister of Health of 24 January 2020 amending the regulation on chemical substances, their mixtures, agents or technological processes with carcinogenic or mutagenic effects in the work environment*. Journal of Laws 2020 item 197. Available from: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20200000197 [Accessed: May 01, 2022].
21. Ji, Y., Ren, T., Wynne, P., Wan, Z., Ma, Z. & Wang, Z. (2016) A comparative study of dust control practices in Chinese and Australian longwall coal mines. *International Journal of Mining Science and Technology* 26(2), pp. 199–208.
22. Korban, Z. (2015) Application of the MERIT survey in the multi-criteria quality assessment of occupational health and safety management. *International Journal of Occupational Safety and Ergonomics* 21(3), pp. 365–372.
23. Korban, Z. (2019) Assessing occupational health and safety management quality by means of multi-criteria assessment: A case study. *IOP Conference Series: Earth and Environmental Science* 261(1), 012019.
24. Krzemień, S. & Mocek, P. (1999) *Determination of the occupational risk index characterizing the potential threat arising in underground workings as a result of the impact of coal dust on the human body. Fighting dust hazards in mining*. Mining Mechanization Center KOMAG, SITG KOMAG. Ref. IV, No. 15, pp. 1–9, International Scientific and Technical Conference, Wisła, October 5–7, 1999.
25. Kuczera, Z. & Ptaszyński, B. (2019) Fighting dust in Polish mining. *Mineral Engineering* 21(1/2), pp. 191–187.
26. Laney, A.S. & Weissman, D.N. (2014) Respiratory diseases caused by coal mine dust. *Journal of Occupational and Environmental Medicine* 56 (Suppl. 10), pp. 18–22.
27. Liao, X., Wang, B., Wang, L., Zhu, J., Chu, P., Zhu, Z. & Zheng, S. (2021) Experimental study on the wettability of coal with different metamorphism treated by surfactants for coal dust control. *ACS Omega* 6(34), pp. 21925–21938.
28. Liu, T. & Liu, S.H. (2020) The impacts of coal dust on miners' health: A review. *Environmental Research* 190, 109849.
29. López-Campos, J., Soler-Cataluña, J. & Marc Miravitlles, M. (2019) Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease 2019 report: Future challenges. *Archivos de Bronconeumología* 56(2), pp. 65–67.
30. Lutyński, L. (2021) Zagrożenia pyłem i ich zwalczanie w zakładach przeróbki mechanicznej kopalń węgla kamiennego. *Inżynieria Mineralna* 1(1), pp. 9–12.
31. Maciejewska, A. (2012) Application of infrared spectrometry (FT-IR) for mineral identification of asbestos in bulk samples. *Medycyna Pracy* 63(2), pp. 181–189 (in Polish).
32. Mocek, P. (2002) *Assessment of the risk of occupational diseases in workers employed in underground workings of a coal mine*. PhD thesis. Gliwice, Poland: Silesian University of Technology.
33. Peng, H., Nie, W., Zhang, S., Cheng, W., Liu, Q., Guo, C., Ma, Q., Zhou, Z., Xu, C., Hua, Y. & Zhang, H. (2022) Research on negative pressure jet dust-removal water curtain technology for coal mine cleaner production. *Fuel* 310, 122378.
34. Perret, J.L., Plush, B., Lachapelle, P., Hinks, T.S.C., Walter, C., Clarke, P., Irving, L., Brady, P., Dharmage, S.C. & Stewart, A. (2017) Coal mine dust lung disease in the modern era. *Official Journal of the Asian Pacific Society of Respirology* 22(4), pp. 662–670.
35. Świątkowska, B. & Hanke, W. (2021) *Occupational diseases in Poland in 2020*. Łódź, Poland: Institute of Occupational Medicine. Central Register of Occupational Diseases.
36. Tinkelman, D.G., Price, D.B., Nordyke, R.J. & Halbert, R.J. (2007) COPD screening efforts in primary care: What is the yield? *Primary Care Respiratory Journal* 16(1), pp. 41–48.
37. Tobór-Osadnik, K., Wyganowska, M. & Manowska, A. (2017) Employee attitudes to work safety in Poland's coal mining companies. *Journal of the Southern African Institute of Mining and Metallurgy* 117(1), pp. 41–46.
38. Tomášková, H., Šplíchalová, A., Šlachtová, H., Urban, P., Hajduková, Z., Landecká, I., Gromnica, R., Brhel, P., Pelclová, D. & Jirák, Z. (2017) Mortality in miners with coal-workers' pneumoconiosis in the Czech Republic in the period 1992–2013. *International Journal of Environmental Research and Public Health* 14(3), 269.
39. Torres Rey, C.H., Ibañez Pinilla, M.I., Briceño Ayala, L., Checa Guerrero, D.M., Morgan Torres, G., Groot De Restrepo, H. & Varona Uribe, M. (2015) Underground coal mining: Relationship between coal dust levels and pneumoconiosis, in two regions of Colombia, 2014. *BioMed Research International* 2015, 647878.
40. WUG (2021) *Assessment of work safety, mine rescue and general safety in connection with mining and geological activities in 2021*. Katowice: Higher Mining Office.
41. Wyganowska, M. (2019) A study of the correlation between seniority and the number of work accidents in mining enterprises between 2003–2017. *IOP Conference Series: Earth and Environmental Science* 261(1), 012058.
42. Xu, J. & Wang, H. (2021) Underground intelligent dry dust collector in the coal mine. *IOP Conference Series: Earth and Environmental Science* 647, 012051.
43. Yang, H.-Y., Shie, R.-H., Chang, C.-J. & Chen, P.-C. (2017) Development of breath test for pneumoconiosis: A case-control study. *Respiratory Research* 18(1), 178.
44. Zhang, C., Wang, X., Li, S., Jiang, B., Zhai, C., Zhu, C. & Ni, G. (2022) Development and application of a new compound wetting agent for coal seam water infusion. *Fuel* 314, 122767.
45. Zhang, Y. (2021) Computer-aided diagnosis for pneumoconiosis staging based on multi-scale feature mapping. *International Journal of Computational Intelligence Systems* 14(1), 191.
46. Zosky, G.R., Hoy, R.F., Silverstone, E.J., Brims, F.J., Miles, S., Johnson, A.R., Gibson, P.G. & Yates, D.H. (2016) Coal workers' pneumoconiosis: An Australian perspective. *The Medical Journal of Australia* 204(11), pp. 414–418.

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