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Assessing the breathing resistance of filtering-facepiece respirators in Polish coal mines: A survey and laboratory study

Angelika Więckol-Ryk[a,*], Alicja Krzemień[a], Fernando Sánchez Lasheras[b]

[a] Central Mining Institute, Department of Industrial Risk Assessment, Plac Gwarków 1, Katowice, 40-166, Poland
[b] University of Oviedo, Department of Construction and Manufacturing Engineering, Calle Pedro Puig Adam, Sede Departmental Oeste, Módulo 7, 33203, Gijón, Spain

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ABSTRACT

Hard coal miners most commonly use filtering-facepiece respirators to protect themselves from hazardous air particles. Prolonged exposure to coal mine dust is the cause of various pulmonary diseases, particularly coal workers' pneumoconiosis. This article presents the results of an assessment of the breathing resistance of filtering-facepiece respirators (FFRs), which are commonly used in underground hard coal mine workings. The results include survey studies and laboratory examinations of the effect of an increase in dust and moisture mass on the breathing resistance of FFRs. The survey was conducted among 150 respondents, who represented three groups of miners: workers who directly handle the material, workers who handle the transport of materials, and technical mining staff. The age of the employees was 21–50 years. In the study, we obtained the miners' opinions on the relevance of the application of respirators, their structural strength and the maximum use period in the arduous conditions of the mine. The laboratory examination results show that both dust and the moisture absorbed by the FFRs considerably affect the increase in breathing resistance. For this reason the time of use of the respirators in underground coal mining conditions is much shorter than expected.

Our study may result in developing technologies to produce new and improved filtering materials and respiratory protection equipment in the mining industry, which will better secure miners against the harmful effect of mine dust.

1. Introduction

The dustiness of the air in hard coal mines is one of the most serious threats facing the mining industry. Long-term inhalation of mine dust, which contains harmful crystalline silica (SiO_2), poses a significant risk of the lung disease called silicosis, which is also known as coal worker's pneumoconiosis (CWP) (Leung et al., 2012; Castranova and Vallyathan, 2000). Silicosis was first recognized in Scottish miners in 1830 (Wallaert and Leroy, 2008). According to the International Statistical Classification of Diseases and Related Health (ICD-10), coal worker's pneumoconiosis is consider an occupational disease (category J60) and represents the most common type of pneumoconiosis in Poland (Niewiadomska and Kowalska, 2014).

Chronic silicosis usually occurs 10 years or more after the silica exposure; therefore, it has been the most frequently diagnosed disease among retired miners. Most studies on CWP in Polish coal mines and the use of appropriate respiratory protective equipment were conducted in the 1980s and 1990s (Marek, 1981; Marek and Starzyński, 1994; Starzyński et al., 1996; Marek and Lebecki, 1999).

This risk of silicosis is caused by the difficulty to reduce dustiness to a completely safe level. The worldwide statistics show that the highest number of cases of the disease occurs in the mining industry in China. Poland is sixth among the nine countries classified in this category (Yan-Giang et al., 2011).

It is well-known that CWP is caused by the inhalation of mine dust, which contains a mixture of SiO_2 in concentrations of 2%–10%, inorganic minerals and trace metals, such as boron, cadmium, copper, nickel, iron, antimony or lead (Niewiadomska and Kowalska, 2014; Castranova and Vallyathan, 2000). As demonstrated by the study at Nofer Institute of Occupational Medicine in Poland (NIOM), miners who are directly involved in cutting and transporting coal are most exposed to inhaling the harmful dust (Mikołajczyk et al., 2010). The ratio of observed cases of silicosis in the underground coal mining industry to that in the entire mining industry in Poland has exceeded 90% for many years (Patyńska, 2017). In recent decades, the number of workers employed in Polish coal mines has decreased, but the percentage of silicosis has steadily increased compared to other occupational diseases (Fig. 1). Considering the period of the onset of symptoms, these figures reflect the working conditions in Polish coal mining in the 1990s.

* Corresponding author.
E-mail addresses: awieckol@gig.eu (A. Więckol-Ryk), akrzemien@gig.eu (A. Krzemień), sanchezfernando@uniovi.es (F. Sánchez Lasheras).

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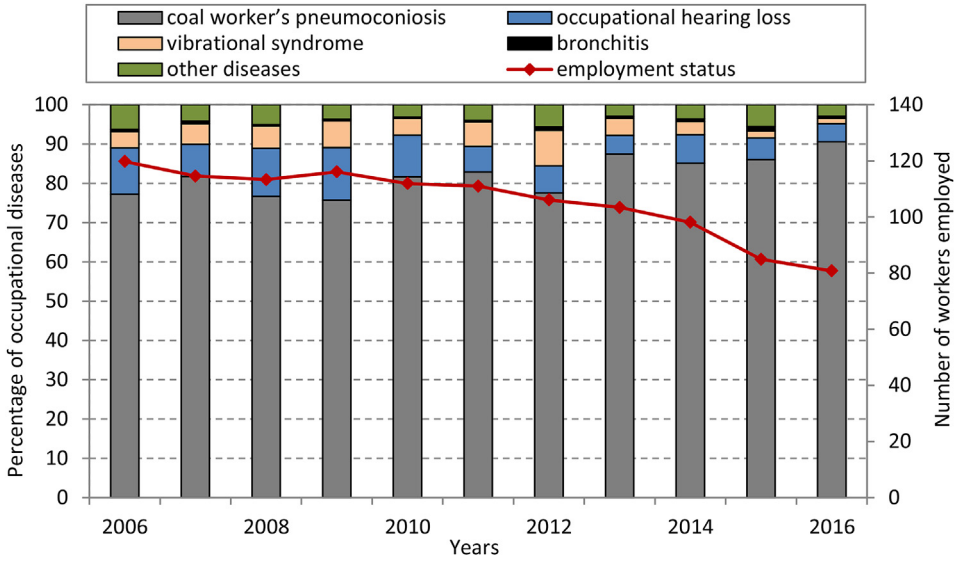

Fig. 1. Occupational diseases in Polish coal mining (WUG - State Mining Authority, 2017).

Based on the data published by the NIOM in 2016, 23% of all registered occupational diseases in Poland was associated with the coal mining sector. This figure is notably high, considering that only 1.6% of the working population is employed in the mining and quarrying sector (Central Statistical Office, 2017).

The Polish legislation (Ministry of Labour and Social Policy, 2014) specifies the safe amounts of harmful factors that are acceptable at workstations, including crystalline silica, as the "highest permissible concentrations" (HPC) for total and respirable dust (Table 1). According to the retrieved data at the end of 2014, in 79% of longwall panels in underground hard coal mines, the concentration of dust exceeded the HPC value at the air inflow to the longwall panel.

The preventive measures to combat the dust hazard in the mining industry include implementation methods of dedusting and damping mine air (Prostański, 2013, Council Directive 89/686/EEC). If the application of these methods does not reduce the dust below the HPC value, each member of the staff must use personal protective equipment, such as respiratory devices. The most commonly applied systems are single-use filtering-facepiece respirators (hereafter called "respirators") and elastomeric facepiece with replaceable filter elements. The rules to select such equipment are specified by the European Union's legal requirements (Council Directive 89/686/EEC). The use of respirators in coal mines is not new, but the comfort and fit are important performance characteristics that respirator designers, users and standard developers consider. The design of the FFRs affects the psychophysical parameters of their users. According to (Guo et al., 2008), the use of respirators without exhalation valves, which close when air is inhaled and open when air is exhaled, may increase the heart rate or microclimate (temperature and humidity) inside the mask.

The European legislation (UNE-EN 149:2001 + A1, 2010) defines three classes of respirators: FFP1, FFP2 and FFP3, which offer different levels of protection to a wearer from the lowest to the highest. In the highly polluted atmosphere of underground mining operations, it is permissible to use the FFP2 and FFP3 classes of dust respirators. Unfortunately, the use of these respirators induces difficulties in breathing, which reduces the comfort of work. The respirators press against the face; therefore, breathing requires additional effort from the worker, who is already performing difficult physical work. Breathing difficulties and physical discomfort are the major disadvantages associated with the use of the FFRs. In recent years, almost all information on the effectiveness of respirators in working conditions was based on survey research (DeSieghardt and Harris, 1971; Reist et al., 1972) or laboratory study (Meyer et al., 1997; Krzyżanowski and Majchrzycka, 1997; Majchrzycka, 2000; Grima-Olmedo et al., 2014). According to (Reist et al., 1972), 511 coal miners of 47 different mining operations indicated the reasons for discomfort to be a cumbersome respirator, perspiration, head harness, size and dust inside the respirators. The measurements of leaks and their effect on the thermal and physical work (Meyer et al., 1997) show that the acceptable time to use an FFR while doing heavy work is approximately 1 h. Older workers and non-smokers were more sensitive to the mask discomfort than others doing the identical work.

A coal dust penetration test of a few types of FFRs in three efficacy classes (FFP1, FFP2 and FFP3) was conducted by (Grima-Olmedo et al., 2014). The dust concentrations simulated the concentrations that might be found at a coalface (800 mg/m^3). The results showed that the studied respirators did not protect workers as well as they should have. In most cases, the measured penetration was higher than that the permitted value by the EU legislation (UNE-EN 149:2001 + A1, 2010).

Based on our previous survey (Więckol-Ryk and Krzemień, 2015), according to the Polish miners, the most important features of filtering respirators are their tightness of fit and humidity resistance. As revealed by prior laboratory research, the dynamics of changes in the breathing resistance of filtering fibers is determined to a considerable degree by the dust type and concentration, type and structure of the filtering material and relative humidity of the air (Krzyżanowski and Majchrzycka, 1997; Majchrzycka, 2000). A study of the U.S. National Institute for Occupational Safety and Health (NIOSH) on surgical respirators demonstrated that the moisture from the exhaled air did not considerably affect the breathing resistance of FFRs (Roberge et al., 2010).

The conditions in underground mine workings, where the temperature reaches 30 °C and the humidity rate can exceed 90% (Drenda et al., 2013), make the implementation of FFRs particularly arduous. In

Table 1
Highest permissible concentrations of crystalline silica in coal mine dusts in Poland (Ministry of Labour and Social Policy, 2014).

Coal mine dusts	HPC of SiO_2 in total dust mg/m^3	HPC of SiO_2 in respirable dust mg/m^3
with SiO_2 above 50%	1.0	0.3
with SiO_2 in the range of 10–50%	2.0	1.0
with SiO_2 in the range of 2–10%	4.0	2.0
with SiO_2 below 2%	10.0	–