CHEMICAL ENGINEERING TRANSACTIONS

VOL. 108, 2024

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Carlo Pirola, Antonio Espuña

ISBN 979-12-81206-08-3; **ISSN** 2283-9216

DOI: 10.3303/CET24108012

Risk Analysis and Control Strategies for Dust Exposure in Aggregate Crushing Plants

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This research aims to propose preventive measures for addressing health issues caused by dust exposure in a construction aggregate crushing plant. Initially, excessive dust emissions from stone crushing and vehicular traffic were identified. Monitoring using the Thermo Scientific VFC-PM10 air sampler showed a concentration value (659.68 µg/m^3) exceeding ECA and WHO standards significantly. The VPC300 particle counter detected hazardous concentrations of fine dust particles (0.3 µm to 5.0 µm), indicating high exposure intensity. The quarry, the raw material source, exhibited a high SiO_2 concentration (95.67% to 98.05%). A worker survey assessed personal susceptibility factors for dust-related health conditions. Control measures to mitigate dust emissions and administrative actions to reduce occupational diseases have been proposed based on these findings.

1. Introduction

Mining operations require large amounts of raw materials and heavy machinery, leading to challenges in dispersing and removing suspended particles due to factors like depth and ventilation. Dust emissions present environmental and health risks to workers and nearby communities (Brauer et al., 2019; Gautam et al., 2018).
The Forum of International Respiratory Societies (FIRS) estimates that at least 65 million people have chronic respiratory diseases like COPD, causing 3 million deaths annually, ranking it as the third leading cause of death globally. In 2014-2015, approximately 33,000 workers faced respiratory problems, resulting in 664,000 lost workdays, averaging 13 days per case (Delabre et al., 2023). Poor air quality in the workplace poses a significant risk to lung health, leading to mortality, disability, and absenteeism due to occupational diseases. Over 50 million workers are affected by such lung conditions. (Rathebe, 2023).
Exposure to mineral dust, including silica, can give rise to diseases such as silicosis and pneumoconiosis. These illnesses are preventable through the management of emissions and keeping them below occupational exposure thresholds (Rahimi et al., 2023). A study in Iran (2016-2017) revealed alarming levels of crystalline silica in crushing mines, posing serious health risks to workers. In Peru, silicosis is common among miners due to crystalline silica exposure, leading to lung issues and increased lung cancer risk (Wong Lau et al., 2023).
At mining firms like Sociedad Minera Corona in Huancayo, silica dust emissions surpass permissible limits by 35 times, harming worker health and the environment. Inadequate engineering controls and ineffective dampening methods exacerbate the issue. Similarly, TITAN's Belen plant in Peru releases significant dust levels, compromising worker health due to ineffective suppression measures (Balarezo-Rodriguez et al., 2023).
In the realm of workplace safety and health, various processes, techniques, and management tools are employed to identify and assess risks, allowing for the implementation of appropriate controls to prevent occupational diseases (Gracia et al., 2022; Zoltán Macher et al., 2023). Practices aimed at risk mitigation have become integral to environmental management systems, aiming to minimize their adverse impacts. One effective method is the dry fog dust suppression system, which notably decreases dust and silica concentrations in work areas, reducing free silica in dust from 3.61 to 4.80%. Apart from promoting cleaner mining practices

Paper Received: 15 January 2024 ; Revised: 29 February 2024 ; Accepted: 15 March 2024
Please cite this article as: Garcia-Granda L.H., Sanchez-Shapiama W.A., Albujar-Verona C.E., Alvarado-Silva C.A., de Azevedo Silva F., 2024, Risk Analysis and Control Strategies for Dust Exposure in Aggregate Crushing Plants, Chemical Engineering Transactions, 108, 67-72 DOI:10.3303/CET24108012

and environmental conservation, this system offers advantages in terms of maintenance ease and energy efficiency, while also reducing overall maintenance costs (Saurabh et al., 2022).
Mining roads also contribute to particulate matter emissions; hence, various dust suppressants are employed for effective control. Among these are bituminous products such as cut asphalt and asphalt emulsions, which effectively contain dust and have a lasting effect (Brauer et al., 2019).
In the Lambayeque region, non-metallic mining activities produce dust containing silica, posing risks to workers. Data suggests around 177,692 workers in Peru could be vulnerable to this contaminant. At a construction aggregate crushing plant in Lambayeque, operations proceed without sufficient dust suppression and control measures, particularly during material handling and transportation, leading to heightened levels of dust pollution in the workplace (Balarezo-Rodriguez et al., 2023).
The company disregards occupational health guidelines mandated by law, neglecting assessments for occupational diseases and lacking records to demonstrate adherence to medical examination protocols. Limited access to monitoring reports impedes evaluation of air quality and presence of chemical contaminants. This investigation aims to identify primary risks in raw material crushing companies and propose preventive measures against silicosis, focusing on a specific case in Lambayeque, Peru.

2. Methodology

To identify and recognize the hazards in the crushing process, the Control Check List from the Protocol for monitoring the health of workers and jobs exposed to SiO_2 dust in construction (Figure 1.C), developed by the Public Health Institute of Chile, was executed. By the other hand, air quality sampling will be conducted to prevent and assess health risks, adhering to the standardized technical criteria in the National Protocol for Monitoring Environmental Air Quality, as approved by DS N° 010-2019-MINAM. The primary focus will be on parameters such as particulate matter <10 µm and <2.5 µm, which are associated with metal mineral extraction activities, these emissions were monitored using the Thermo Scientific high-volume air sampler, VFC-PM10 (Figure 1.A).

Figure 1: A) Monitoring of particles smaller than 5.0 micrometers. B) Environmental monitoring parameters. C) Dust settled in facilities, dispersion due to vibrations. D) Barometric pressure (mmHg).

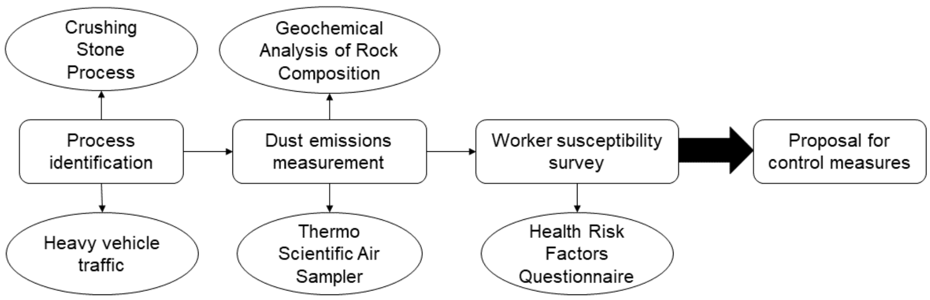

Figure 2: Research execution methodology

To quantify the amount of inhalable dust particles suspended in the workplace atmosphere an alternative method will be chosen to enable the analysis of the silicon dioxide proportion in the sampled material. This will be achieved through chemical analysis and the calculation of metal concentrations in the PM2.5 filters (Figure 1.B). Table 1 shows the limits for particle concentration.To ensure data quality, the testing will be performed in a laboratory accredited by INACAL (National Quality Institute of Peru) using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) method. Finally, the "QUESTIONNAIRE ON RISK FACTORS IN LUNG HEALTH" will be administered to assess the acute effects resulting from prolonged exposure to high levels of particulate matter (Rahimi et al., 2023). Based on the results and supported by bibliographic references, the implementation of engineering and administrative controls is recommended to mitigate exposure to dust contaminants. The entire methodological process is illustrated in Figure 2.

Table 1: Alarm limits for particle concentration

Channel	Green (regular)	Yellow (alarm)	Red (limit)
0.3µm	0 – 100,000	100,001 – 250,000	250,001 - 500,000
0.5µm	0 – 35,200	35,201 – 87,500	85,701 – 175,000
1.0µm	0 – 8,320	8,321 – 20,800	20,801 – 41,600
2.5µm	0 – 8,320	546 – 1,362	1,363 – 2,724
5.0µm	0 – 545	184 – 483	484 – 966
10µm	0 – 68	69 – 170	170 – 340

Source: TRT–BA-PC220-003 particle counter manual (Rathebe, 2023).

3. Results and discussion

3.1 Diagnosis

Dust control systems and working conditions.
Initially, a dust control checklist assessed design and machinery, revealing issues: crushers emitted excessive dust due to demand; lack of collectors or humidification systems in emission areas (Figure 1.D); persistent vehicle emissions despite road irrigation. Administratively, no Occupational Health and Safety Management System (OHSMS) exists, leading to the absence of an Occupational Health Plan incorporating ILO guidelines to reduce Silicosis incidence. Additionally, no procedures establish standards for removing settled dust in plant facilities, including floors, beams, etc.

Dust contaminant exposure assessment.
Dust concentration. Particulate Matter (PM) with diameters less than 10 µm and less than 2.5 µm were sampled. Samples were collected using the Thermo Scientific High Volume Air Particle Sampler, VFC-PM10, operating at an air flow rate of 1133 m³/min for 10 µm particles. The analysis revealed a PM10 concentration of 659.68 µg/m³, exceeding the environmental standard ECA N° 003-2017-MINAM for air by more than 6 times and surpassing WHO guidelines by more than 13 times. Occupational exposure standards typically focus on chemical contaminants (Keleş & Sarver, 2023). In this context, silica was chosen as a representative contaminant for concentration comparison and evaluation.

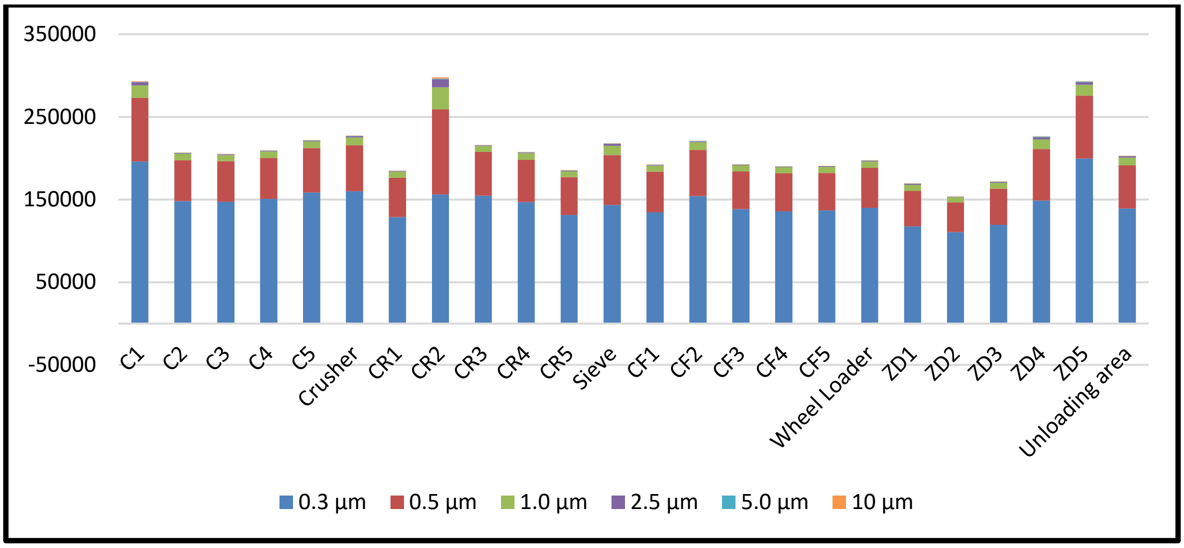

Figure 2: Dust particles in the respirable fraction.

Number and size of particles < 10µm. Cumulative monitoring revealed the presence of particles with diameters of 0.3 µm, 0.5 µm, 1.0 µm, 2.5 µm, 5.0 µm, and 10 µm in high concentrations within the workplace environment, referencing ISO 14644 (see Figure 2). Table 1 demonstrates that the intensity levels exceed the alert range established for measurement evaluation.

Silica concentration at exposure. According to INGMMET in (Carpio et al., 2017), Four samples (14d-RNM – 09, 11, 14, 15) from the stratigraphic unit, representing the quarry for raw material extraction (mainly igneous rock over 3" for construction), were analyzed (Table 2). Results showed SiO2 concentrations of 95.67% to 98.05% and low Fe_2O_3 levels (0.11% to 0.35%). Al_2O_3, Na_2O, K_2O, CaO, MgO, and TiO_2 concentrations ranged from 0.66% to 0.89%, less than 0.02%, 0.08% to 0.14%, 0.11% to 0.8%, less than 0.01% to 0.03%, and 0.09% to 0.15%, respectively. These materials serve various sectors like construction, ceramics, steel, and ferro-silicon production. Analysis of quartz sandstone samples from the quarry indicates high silica content. The Chilean Ministry of Health's 2015 protocol warns about health risks linked to silica exposure, particularly in operations involving materials with SiO_2 content exceeding 30% but not surpassing 75%, or with Quartz presence (100% SiO_2) (Irenge et al., 2023).

Table 2: Metal concentration in sample.

Sample	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	Na_2O %	K_2O %	CaO %	MgO %	TiO_2 %	MnO %	P_2O_5 %	LOI %	TOTAL %
14d-RNM-09	97.29	0.24	0.66	<0.02	0.10	0.24	0.02	0.09	<0.01	<0.01	0.96	99.59
14d-RNM-11	98.05	0.25	0.59	<0.02	0.12	0.11	<0.01	0.09	<0.01	<0.01	0.06	99.28
14d-RNM-14	95.67	0.11	0.89	<0.02	0.08	0.80	0.03	0.15	<0.01	0.51	0.83	99.07
14d-RNM-15	97.56	0.35	0.82	<0.02	0.14	0.34	0.02	0.15	0.02	0.05	0.52	99.96

Source: Prepared from INGEMMET laboratory results (Carpio et al., 2017)

Symptom Survey.

The worker survey found that only 12% experienced symptoms such as frequent daytime cough or expectoration for at least four days a week, lasting three consecutive months per year for four to five years. Conversely, 44% reported breathing difficulties, including shortness of breath during physical activities and daily routines.

3.2 Prevention Measures

Dry Fog Dust Control System

General description. To tackle excessive dust during the crushing process, the most effective solution is employing the dry fog method for dust suppression. This choice is preferred over traditional equipment due to its consistent production of fine water droplets. Moreover, materials for this system are readily available and cost-effective compared to other options (Irenge et al., 2023).

To implement the proposal, a plan involves using a 2 HP 100-liter air compressor as the compressed air source and a dedicated 2500-liter tank for the system (see Figure 1.D). Six gravity guns with high-pressure nozzles for air and water intake will be utilized. It's advised to install this system near the vibrating screens, where the most particulate material is released (refer to Figure 3.B).

Figure 3: A) Spray gun. B) Dry fog application. C) Treated area.

System operation scheme. The dry fog system operates based on the principles of the Venturi effect, which describes how air traveling at a constant speed through a duct, upon encountering a narrower section, accelerates while reducing pressure (Saurabh et al., 2022). In this case, a high-pressure gravity spray gun will be employed, designed to carry a small amount of water through the airflow towards the nozzle (see Figure 3.A). Among the various preventive measures for suppressing particulate matter, the dry fog system, with its fine water droplets dispersed by controlled airflow, stands out as a cost-effective solution adaptable to the existing plant structure. It also reduces dust emissions from the treated area (refer to Figure 3.C). These findings align with (Bello et al., 2019), which implemented a dry fog system to reduce particulate matter concentrations, showcasing similarities between their results and our proposal. In light of these considerations and potential outcomes, it's evident that these preventive measures are highly efficient.

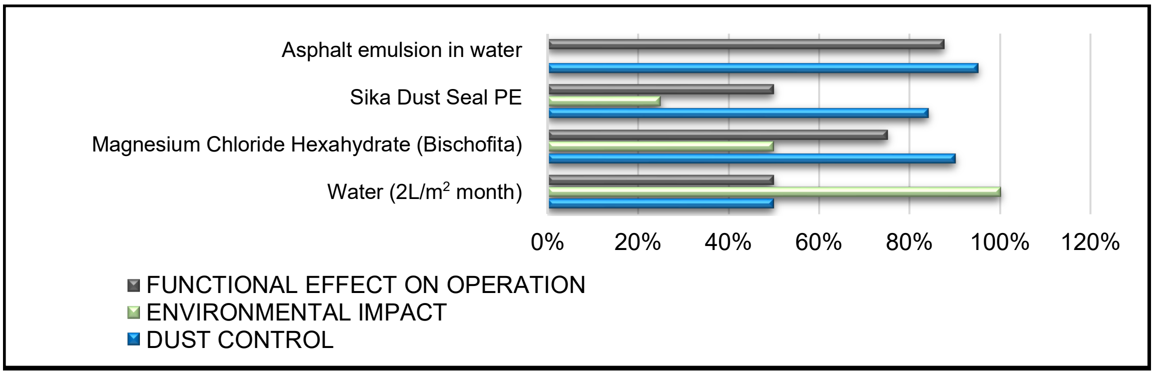

Figure 4: Operational and Environmental Efficiency.

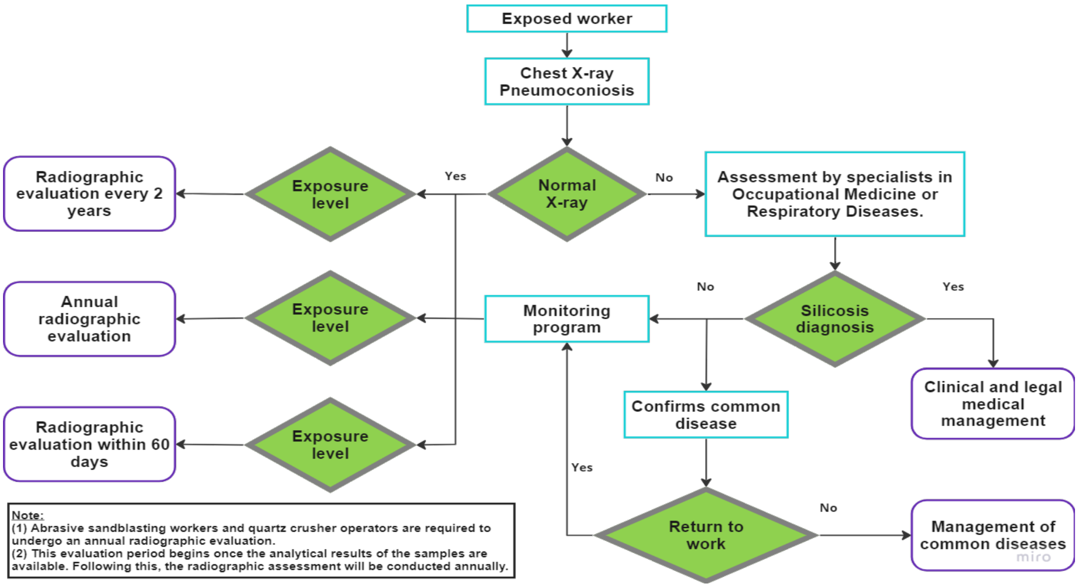

Figure 5: Preventive clinical management of Silicosis.

<u>Chemical Stabilization at the Rolling Folder Level</u>

Chemical soil stabilization utilizes quick-setting asphalt emulsion in water to improve soil geotechnical properties, such as permeability and durability, while reducing dust by 95%. This method was chosen for its effectiveness in dust reduction, environmental impact, long-term performance, cost-effectiveness, and water conservation. Figure 4, drawing on technical data from Shafiei et al. (2019), assesses the effectiveness of chemical stabilizers in surface treatment to reduce dust, considering their performance under operational conditions and environmental impact. Among the three most cost-effective options suitable for the company's operations, characterized by fewer than 200 daily vehicles, quick-setting asphalt emulsion in water emerges as the optimal choice. This is primarily due to its 0% environmental toxicity, 88% operational compatibility, and 5% higher efficiency in dust control compared to $MgCl_2$ hexahydrate, which achieves 90% efficiency. Magnesium chloride hexahydrate, available in the Peruvian market for high-traffic roads, carries a 50% chance of suitability for local environmental conditions and a 50% chance of causing adverse environmental impacts, both triggered by rainfall. Lastly, to address inherent risks associated with company operations, it's crucial to enforce mandatory regular medical examinations for workers to alleviate any symptoms they may experience. We recommend implementing chest radiography studies at varying frequencies, considering the prevalence of common diseases such as silicosis (refer to Figure 5).).

4. Conclusions

The text addresses high dust emissions from various industrial sources, notably during activities like crushing, material classification, discharge, flow changes, and transportation, with access roads also contributing significantly. These emissions exceed air quality standards, posing health risks to workers exposed to silica and quartz, elevating the risk of diseases like Pneumoconiosis, acute silicosis, lung cancer, and respiratory cardiac conditions, especially in individuals with factors such as age, smoking history, and pre-existing health issues. To tackle this issue, two engineering controls are recommended: the Dry Fog Dust Control System and Chemical Soil Stabilization using Asphalt Emulsion. These solutions can be tailored to match process design and operational characteristics, offering cleaner, lower-risk alternatives for health and the environment. A monitoring protocol is also established to ensure compliance with occupational health and safety standards in the mining sector, aiming to prevent silica-related diseases and maintain safe conditions for employees. In summary, high dust emissions and silica exposure in industrial settings are significant health and environmental concerns, with the text providing recommendations for control measures and monitoring to address these issues.

References

Balarezo-Rodriguez, K., Albújar-Verona, C. E., & Alvarado-Silva, C. A. (2023). Metodología para la Estimación de Costos de Accidentes e Incidentes Laborales. Estudio de Caso en el Rubro de Transportes de Materiales Peligrosos. *Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology*, *July*. https://doi.org/10.18687/LACCEI2023.1.1.1394

Bello, A., Mugford, C., Murray, A., Shepherd, S., & Woskie, S. R. (2019). Characterization of Occupational Exposures to Respirable Silica and Dust in Demolition, Crushing, and Chipping Activities. *Annals of Work Exposures and Health*, *63*(1), 34–44. https://doi.org/10.1093/annweh/wxy089

Brauer, D. A., Giubergia, A. A., & Gil-Costa, V. (2019). Products evaluation for controlling enviroenmental dust in mining roads. *Minería y Geología*, *35*(2), 165–182. https://doi.org/10.18050/rev.mg.v35i2.1412

Carpio, M., Torre, J., & Fuentes, J. (2017). Prospeccion de Recursos de Roca y Minerales Industriales en la Región Lambayeque. In *INGEMET - BoletÍn: Vol. N° 41* (Issue Geología Económica).

Delabre, L., Houot, I.-T., Burtin, A., & Pilorget, C. (2023). Occupational exposure to silica dust in France: an ongoing concern. *Scandinavian Journal of Work, Environment & Health*, *49*(7), 526–534. https://doi.org/10.5271/sjweh.4105

Gautam, S., Patra, A. K., Sahu, S. P., & Hitch, M. (2018). Particulate matter pollution in opencast coal mining areas: a threat to human health and environment. *International Journal of Mining, Reclamation and Environment*, *32*(2), 75–92. https://doi.org/10.1080/17480930.2016.1218110

Gracia, J., Acevedo, P., & Cabeza, I. (2022). Health and Safety Management System in Methalmechanic Sector. *Chemical Engineering Transactions*, *91*(April), 253–258. https://doi.org/10.3303/CET2291043

Irenge, C. A., Bushenyula, P. K., Irenge, E. B., & Coppieters, Y. (2023). Participative epidemiology and prevention pathway of health risks associated with artisanal mines in Luhihi area, DR Congo. *BMC Public Health*, *23*(1), 1–14. https://doi.org/10.1186/s12889-023-15020-3

Keleş, Ç., & Sarver, E. (2023). Respirable silica particles in coal mine dust: An image library dataset collected using scanning electron microscopy with energy dispersive X-ray spectroscopy. *Data in Brief*, *51*, 109656. https://doi.org/10.1016/j.dib.2023.109656

Rahimi, E., Shekarian, Y., Shekarian, N., & Roghanchi, P. (2023). Investigation of respirable coal mine dust (RCMD) and respirable crystalline silica (RCS) in the U.S. underground and surface coal mines. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-022-24745-x

Rathebe, P. C. (2023). Occupational exposure to silicon dioxide and prevalence of chronic respiratory symptoms in the cement manufacturing industries: A review. *Journal of Public Health Research*, *12*(4). https://doi.org/10.1177/22799036231204316

Saurabh, K., Chaulya, S. K., Singh, R. S., Kumar, S., & Mishra, K. K. (2022). Intelligent dry fog dust suppression system: an efficient technique for controlling air pollution in the mineral processing plant. *Clean Technologies and Environmental Policy*, *24*(4), 1037–1051. https://doi.org/10.1007/s10098-020-01991-z

Shafiei, M., Ghasemian, A., Eslami, M., Nojoomi, F., & Rajabi-Vardanjani, H. (2019). Risk factors and control strategies for silicotuberculosis as an occupational disease. *New Microbes and New Infections*, *27*, 75–77. https://doi.org/10.1016/j.nmni.2018.11.002

Wong Lau, A., Perez Pineda, J., & DeLouise, L. A. (2023). Immunomodulatory effects of nanoparticles on dendritic cells in a model of allergic contact dermatitis: importance of PD-L2 expression. *Scientific Reports*, *13*(1), 15992. https://doi.org/10.1038/s41598-023-42797-5

Zoltán Macher, G., Beke, D., & Torma, A. (2023). Integrated Analysis and Assessment of the Hungarian Regions in Terms of Health Problems and Waste Management Challenges caused by Asbestos. *Chemical Engineering Transactions*, *107*(April), 361–366. https://doi.org/10.3303/CET23107061