The Indonesian Journal of Occupational Safety and Health
2024, 13 (1): 109-115
p ISSN: 2301 8046, e ISSN: 2540 7872
http://doi.org10.20473/ijosh.v13i1.2024.109-115

ORIGINAL ARTICLE

Risk Assessment of Respirable Dust Exposure to Workers in the Mineral Ore Processing Industry

Arif Susanto[1,2,3], Edi Karyono Putro[3,4], Saskia Nur Fadhilah Kusnadi[3,5], Danny Rosalinawati Mak'dika Santoso[3], Anthony Androful Manuel[6]

[1]Master in Applied Occupational Health and Safety, Vocational College, Universitas Gadjah Mada, Indonesia
[2]Green Technology Research Center, Doctorate Program in Environmental Science, School of Postgraduate Studies, Universitas Diponegoro, Indonesia
[3]Department of Health Safety Environmental, Concentrating Division of PT Freeport Indonesia, Indonesia
[4]Doctorate Program in Environmental Engineering, Faculty of Civil-Planning-Earth Engineering, Institut Teknologi Sepuluh Nopember, Indonesia
[5]Department of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia
[6]Department of Technical Service, Concentrating Division of PT Freeport Indonesia, Indonesia

ABSTRACT

Introduction: The mineral ore processing industry is a sector that can generate pollutants in the form of dust during the production, commonly known as respirable dust. This dust can enter the upper respiratory tract and lungs, thereby causing health problems to employees working in the mineral ore processing industry. This study aims to investigate health risks associated with exposure to dust in the mineral ore processing industry. **Methods:** Environmental Health Risk Analysis (EHRA) was used to assess dust exposure over the previous three years, following the NIOSH Manual of Analytical Methods (NMAM) 0600 for dust sampling measurement. **Results:** Seven locations with high dust emissions were considered for this study. The results of the respirable dust sampling showed that the concentrations in the previous three years ranged from 1,823 to 6,109 mg/m3, followed by a decrease in the following year to 0.049 to 2,715 mg/m3. Meanwhile, in the final year, the concentration of respirable dust ranged from 0.094 to 1.341 mg/m3. The calculated risk quotient (RQ) value for the previous three years remained below 1, indicating safety. **Conclusion:** Athough respirable dust was considered safe in the previous year, it is important to constantly control exposure due to continued high levels and the possibility of future increases.

Keywords: EHRA, mining industry, respirable dust, RQ

Corresponding Author:
Arif Susanto
Email: arifsusanto@mail.ugm.ac.id
Telephone: +6281320317301

INTRODUCTION

Air pollution occurs when human activities release various components into the surrounding air, often in excess of established air quality standards (Government of Indonesia, 2021). This pollution can cause a number of health problems, with respiratory problems being a prominent concern, leading to discomfort while breathing (A'yun and Umaroh, 2023). Air pollution is a pervasive issue that affects various sectors, including the mining industry (Trianisa, Purnomo and Kasiwi, 2020). In the mining industry, mineral ore production involves the use of equipment, such as crushers to crush ore-bearing rocks. These devices can produce dust containing tiny particles smaller than five microns, thereby contributing to air pollution and posing health risks to workers (Wippich *et al*., 2020)

The data from 2021 concerning respirable dust levels in the Concentrating Division of PT Freeport Indonesia (PTFI) recorded a respirable dust level measurement of 6.109 mg/m³. This measurement

Cite this as: Susanto, A. *et al*. (2024) 'Risk Assessment of Respirable Dust Exposure to Workers in the Mineral Ore Processing Industry', *The Indonesian Journal of Occupational Safety and Health*, 13(1), pp. 109-115.

 doi:10.20473/ijosh.v13i1.2024.109-115. Received September 17, 2023; 1st revision January 29, 2024; 2nd revision February 07, 2024; Accepted March 13, 2024; Published: April 2024. Published by Universitas Airlangga.

exceeds the permissible exposure limit and poses a potential threat to the health of workers, leading to dust-related diseases with prolonged exposure (PT Freeport Indonesia, 2023). In 2019, the International Labour Organization (ILO) reported that hundreds of millions of workers experienced occupational accidents and illnesses due to exposure to hazardous substances in their workplaces (International Labour Organization, 2019). Research has consistently shown a positive correlation between inhaled dust exposure among industrial workers and impaired lung function. The results showed a statistically significant correlation with a p-value of 0.02 and an odds ratio (OR) of 5.833, with a 95% confidence interval (CI) of 1.865 ± 18.245. The likelihood of respiratory impairment for individuals working in environments where respirable dust concentrations exceed the established standard of 3 mg/m³ is 68.6% (Darwel *et al*., 2022; ACGIH, 2023).

Several factors contribute to the development of dust-induced respiratory diseases or disorders, including particle size, concentration, shape, solubility, chemical properties, and duration of exposure. Individual factors such as lung defense mechanisms, anatomy and physiology of the respiratory tract, and the immunological characteristics of workers, also play a significant role in influencing the development of these diseases (Anes, Umboh and Kawatu, 2015). Diseases or disorders caused by work or exposure in the work environment, including those caused by dust exposure, are categorized as Occupational Diseases (OD), as outlined in the Presidential Regulation No. 7 of 2019.

Given the aforementioned issues, it is necessary to investigate the exposure to respirable dust in the mining industry, with a particular emphasis on ore processing units, which include both crushing and milling. This research aims to determine the level of exposure and to identify preventive measures to protect the health of workers in this sector. Furthermore, it aligns with occupational health initiatives outlined in Article 98 of Law No. 17 of 2023 concerning occupational health, which emphasizes the imperative commitment to the well-being of workers (President of Republic of Indonesia, 2023).

METHODS

This study was conducted between June and August 2023 within the operational boundaries of the mining industry and focuses on the Concentrating Division at PTFI, specifically the crushing and milling units. Secondary data collected from dust measurements over the previous three years were used. Subsequently, a sampling pump operating at a flow rate of 2.0 L/minute, tubing, and a 5µ PVC filter cassette were used to conduct dust measurements. The pump was calibrated and an observation area was selected.

Sampling points were selected to represent conditions in the work area. Sampling was performed according to the 2017 NIOSH 0600. The equipment was placed at a height of 1.5 meters above the ground during the sampling in order to cater for breathing zones. Temperature, humidity and wind speed were subsequently monitored during the measurements (The National Institute for Occupational Safety and Health, 2017). The analysis was conducted using the EHRA method.

EHRA is a method used to evaluate and analyze the health risks associated with dust exposure for mining workers. The techniques included hazard identification, dose-response analysis, and exposure analysis. This study adopted a quantitative cross-sectional approach. The analysis was based on the EHRA method as shown in Figure 1. In addition to EHRA, the dose-response analysis included the use of a reference concentration (RfC), reference dose (RfD), and slope factor (SF) adjusted for specific sources of exposure. In terms of non-carcinogenic effects from respirable dust, the RfC was set for inhalation, while the RfD was considered during oral uptake or ingestion (Ministry of Health, 2012). The SF was used to assessed concentration levels in relation to carcinogenic exposure. An integrated Risk Information System (IRIS) was used as a reference for developing the RFC, RFD, and SF.

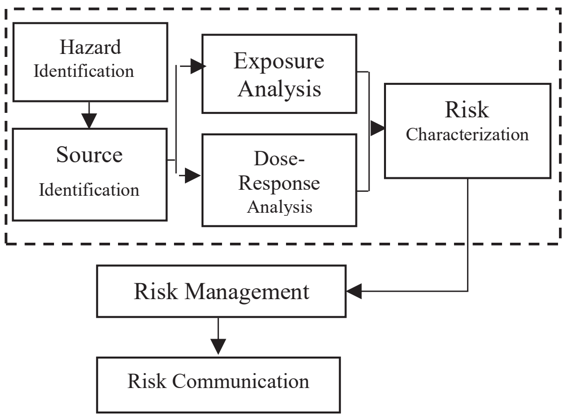

Figure 1. EHRA Method

When reference values were unavailable, values from alternative experimental doses, such as the No Observed Adverse Effect Level (NOAEL), Lowest Observed Adverse Effect Level (LOAEL), or Minimum Risk Level (MRL) were used with careful consideration of anthropometric factors (Maleki *et al*., 2020)

The RfC value was used to calculate risk characterization results, also known as risk quotient (RQ). If the RQ value exceeded 1, further risk management and communication would be required. Typically, RQ was calculated by evaluating the chronic daily intake (CDI) value, which was explained as formula 1. The formula for evaluating non-carcinogenic dust inhalation was expressed as follows:

$$CDI = \frac{C \times R \times t_E \times f_E \times D_t}{W_b \times t_{avg}}$$

Where:
C: risk agent concentration (mg/l)
R: inhalation rate (m3/hour)
tE : exposure time (hours/day)
fE: exposure frequency (day/year)
Dt:: exposure duration (years)
Wb: body weight (kg)
tavg: average time weight period (Dt x 365 days/year for non-carcinogenic substance)

The calculation of risk characterization involved dividing CDI by the dose or concentration of the risk reference. CDI values were derived from the previous exposure analysis, while RfD and RfC values were based on dose-response analysis (Ministry of Health, 2012).

Where:

$$RQ = \frac{CDI}{RfC}$$

CDI represents inhalation calculated using the formula.

RfC represents reference values for risk agents by ingestion exposure.

RESULTS

Hazard Identification

The business process was examined during the identification process. Figure 2 displays the processes that significantly influenced airborne respirable dust concentrations in the mineral ore processing industry. Among these processes, the crushing phase was a major contributor to respirable dust concentrations. This phase entailed the reduction of rock materials from a stockpile, during which mineral ores were crushed and compressed between two iron surfaces to achieve the desired size reduction. During the dry processing phase, respirable dust was generated in the vicinity of the crushing machinery. However, the use of a semi-autogenous mill (SAG) with water resulted in the formation of a concentrate or slurry, which reduced the intensity of respirable dust compared to the crushers.

Following the crushing phase, the materials were ground using a ball mill. This process shared similarities with the SAG process, which also uses water to grind materials previously crushed by a crusher or SAG mill. Although this process may produce respirable dust, the concentration levels are significantly lower than those observed during the crushing phase. After the grinding process, chemical reagents were added to aid in the production of copper and gold concentrates. Given the higher potential for respirable dust concentration in the crusher area, it was crucial to measure respirable dust concentrations in the immediate environment. Specific respirable dust control measures were meticulously applied to conveyor belts responsible for transporting dusty mineral ore (PT X, 2022).

Dose-Response Analysis

According to Table 1, the analysis found that the RfC value is consistent with the non-carcinogenic effects of inhalation exposure (Ministry of Health, 2012). Subsequently, the RfC was determined from available dose-response data and analyzed using the permissible exposure limits (PELs) of the Occupational Safety and Health Administration (OSHA). This analysis showed the importance of adhering to the established exposure limits to

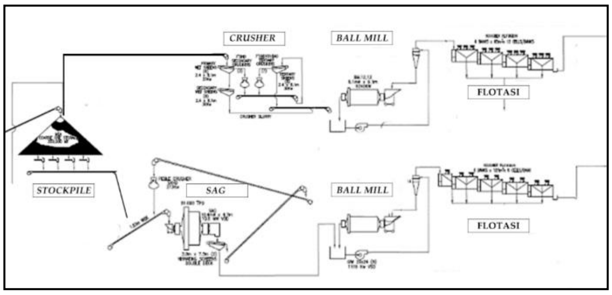

Figure 2. Mineral Ore Process

minimize potential health risks associated with occupational inhalation exposure.

Exposure Analysis

The calculation of exposure analysis was based on respirable dust sampling data from different locations in the mining industry producing high levels of respirable dust. Table 2 shows the calculated concentrations of respirable dust in the mining industry, considering a body weight of 70 kg, an inhalation rate of 0.83 m³/hour, 10-hour daily exposure, a frequency of 250 days per year, and 25-year exposure duration.

Table 1. Dose-response of Respirable Dust

Agent	Dose-Response	Critical Effect and Reference
Respirable dust	5 mg/m3	Respiratory disorders, respiratory tract infection

Table 2. Calculation Results for Respirable Dust Inhalation

Lokasi	Chronic Daily Inhalation (CDI)		
	Year 2020	Year 2021	Year 2023
2BC405	0.217408	0.112156	0.016405
Crusher 14	0.223418	0.026963	0.019572
Crusher 13	0.201084	0.030211	0.007634
Head 2BC306	0.217652	0.013806	0.00934
Head 2BC305	0.211967	0.188902	0.03143
Feed Point 2BC301	0.148052	0.003979	0.01072
Discharge 2BC411	0.496132	0.220494	0.108907

Table 3. RQ Calculation Results for Respirable Dust

Lokasi	Risk Quotient (RQ)		
	Year 2020	Year 2021	Year 2023
2BC405	4,35E-02	2,24E-02	3,28E-03
Crusher 14	4,47E-02	5,39E-03	3,91E-03
Crusher 13	4,02E-02	6,04E-03	1,53E-03
Head 2BC306	4,35E-02	2,76E-03	1,87E-03
Head 2BC305	4,24E-02	3,78E-02	6,29E-03
Feed Point 2BC301	2,96E-02	7,96E-04	2,14E-03
Discharge 2BC411	9,92E-02	4,41E-02	2,18E-02

Risk Characterization

Table 3 shows that all RQ values were significantly less than 1. This indicated that, for workers in the risk group, assuming an estimated body weight of 70 kg, an inhalation rate of 0.83 m³/hour, 10-hour daily exposure, a frequency of 250 days per year, and 25-year cumulative exposure duration, the associated risk levels were safe as long as the CDI remained less than or equal to the RfC. If RQ exceeded 1, the risk level was considered unsafe, which occurred immediately after the exposure inhalation value exceeded the RfD or RfC.

DISCUSSION

Respirable dust consists of particles ranging in size from 0.5 to 4 microns, which can be easily inhaled during normal breathing and can enter the alveoli of the lungs. This type of dust is mainly generated during production processes in various industries, particularly in mining (Wippich *et al*., 2020). In the mining industry, respirable dust production is significantly attributed to equipment, such as crushers. Previous research has shown that exposure to dust in mineral ore processing and mining industries can potentially cause eye, nose, throat, and skin irritation, occupational diseases, and unpleasant odors (Nuhu, 2012).

Respirable dust can negatively impact the well-being of an individual by affecting various systems and causing symptoms, such as eye itchiness, sensory irritaion, and the accumulation of harmful substances in the body. It can also disrupt the respiratory system, causing respiratory tract irritation, increased mucus production, narrowing of the airways, loss of ciliated cells lining the respiration tubes, damage to epithelial membranes, and difficulty breathing. Furthermore, accumulation of respirable dust within the lungs can lead to chronic conditions that cause discomfort in breathing (Lestari *et al*., 2023). According to Schlünssen *et al*. (2023), these risks are magnified when respirable dust containing particles of silica or asbestos enters the respiratory tract, resulting in silicosis and asbestosis.

In 2020, there was an excess of 3 mg/m³ of respirable dust, which reached 6.109 mg/m³. This increase was attributed to the implementation of air pollution control measures. To address this issue, pollution control technology was applied, namely a dry mist dust suppression system. According to Saurabh *et al*. (2022), this technique ensured that no dust remained after operation, maintained the moisture content in mineral ore material, and was environmentally friendly. The dry fog system used water to create a mist cloud that effectively reduced the amount of dust particles in the air. However, it failed in 2020 during its first implementation. Research has shown that the use of dry fog technology can potentially reduce inhaled dust concentrations by 78% to 93% in workers (Xie *et al*., 2022).

Workers who were continuously exposed to industrial dust experienced the associated hazards. Therefore, a dose-response analysis was performed using RfC, RfD and SF values for materials considered hazardous due to their dust levels. These values were determined based on literature information that aided in understanding how hazardous substances entered the body, the health effects of increasing doses or concentrations, as well as the RfC, RfD, and SF values for the hazardous substances. This study estimated that the dust had an RfC value of 5 mg/m³.

The exposure analysis involved calculating the inhalation of dust substances using both primary and secondary data sources. The analysis, also known as chronic daily inhalation (CDI) or exposure analysis, included data from different locations and years, resulting in a value of less than 1. The result indicated that CDI greatly influenced risk quotient (RQ). The final step in the EHRA process was risk characterization, aimed at determining the level of risk associated with a specified dose or concentration of the risk agent that could potentially affect public health. Furthermore, the calculated respirable dust RQ value, which is less than 1, indicated a safe scenario. As the RQ is below 1, risk management and communication are unnecessary. However, the current hazard prevention must be maintained.

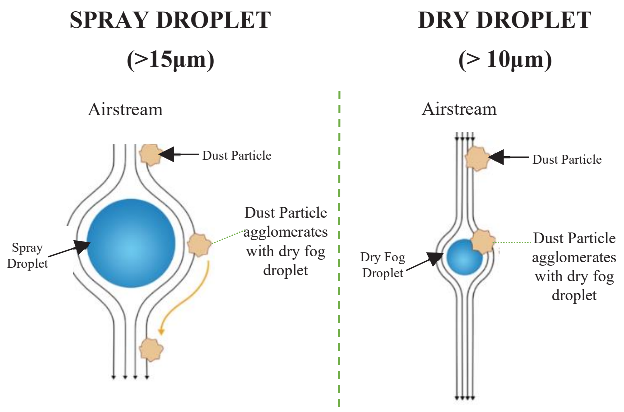

Figure 3. Agglomeration Mechanism

In the mineral ore processing industry, dust control is achieved by implementing a hierarchy of control measures, starting with engineering controls. A dust suppression system is an effective solution to address dust-related challenges prevalent in the mineral ore processing industry. By effectively controlling and reducing air pollution, this system not only protects the health and well-being of workers, but also prioritizes environmental preservation (Hardyanti, Huboyo and Darmawan, 2021). Such measures are essential to maintain a safe, secure, and healthy work environment (Li *et al*., 2021). Due to the potential for dust emissions from mineral ore processing, a system is necessary. The processes involved in the activities include crushing, grinding, and material handling, which release dust particles into the air and pose a risk to workers.

Dry fog systems use water to generate an ultra-fine mist for dust control. The system produces micron-sized water mist particles that are less than 10 µm, which can effectively remove dust particles (Chaulya *et al*., 2021). It is important to note that the principle of dry fog systems is based on agglomeration. During the process, dust dispersed after crushing passes through a conveyor belt and can be carried by the wind, thereby reducing ambient air quality. Furthermore, a dry fog system produces micron-sized water mist that adheres to dust particles, resulting in their precipitation (Roberts and Wypych, 2019). The water mist is released through nozzles positioned above the conveyor belt.

The main component of the dry fog dust suppression system is the dry fog nozzle, which is an air atomizing nozzle. This nozzle uses pressurized air to break down the liquid into small droplets that form a fine mist. Figure 3 illustrates the mechanism of dust capture by smaller water droplets compared to larger ones. This fine mist captures and drops dust particles when sprayed into the air (Yuan *et al*., 2022). The performance of nozzle atomization is influenced by various factors, including the pressure and quanitity of air and water supply, as well as the angle of nozzle installation (Wang, Zhang and Liu, 2019; Li *et al*., 2022).

The implementation of the dry fog system is suitable for the mineral ore processing industry, particularly during the crushing process, which requires dry conditions with low humidity (Saurabh *et al*., 2022). This system introduces quickly evaporating water droplets while maintaining dry mineral ore, adding only less than 0.1% humidity to the mineral ore Chaulya *et al*. (2021), in line with the needs of mineral ore processing.

In addition, this system effective reduces dust concentration in the work environment due to its non-wetting mechanism of the raw material. This system outperforms mist or spray systems which generate larger water droplets and increase humidity levels in mineral ores. In both types of systems, water droplet size ranges between 50 and 200 µm (Saurabh *et al*., 2022).

Workers were also protected from dust when administrative controls and personal protective equipment (PPE) were provided. Examples of the administrative controls included warning systems, signals, signs, labels, instructions, training, education, or work behavior design procedures to reduce the risk of dust exposure (Ajslev *et al*., 2022). Finally, the use of PPE was also implemented by requiring the use of appropriate respiratory protective equipment in certain workplaces with high concentrations of respirable dust (Ahmed *et al*., 2022).

CONCLUSION

In conclusion, the results of the respirable dust sampling consistently showed an average concentration below 3 mg/m³, meeting the established quality standards. However, in 2020, the Discharge 2BC411 location recorded a concentration of 6 mg/m³, surpassing the 3 mg/m³ threshold. This concentration decreased in the following year, falling below 3 mg/m³. The EHRA results for respirable dust indicated an RQ value of less than 1, which categorized the situation as safe and signified a lack of significant risk. Therefore, no new risk communication and risk management measures were required. Although the RQ was deemed safe, the level of inhaled dust still required the continuation of existing risk communication and risk management, including the implementation of hazard controls such as engineering controls, administrative controls, and PPE. Efficient risk management could be achieved by rigorously implementing standard operating procedures (SOPs). At the same time, risk communication played a crucial role in raising awareness and educating workers about the hazards associated with respirable dust exposure.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Anthony A. Manuel, the Vice President of Concentrating Division, and the participating organizations for their contributions to this study. This study was carried out under the auspices of the HSE Department, Concentrating Division of PT Freeport Indonesia, and sponsored by the Environmental and Industrial Health Project Section.

REFERENCES

A'yun, I. Q. and Umaroh, R. (2023) 'Polusi Udara dalam Ruangan dan Kondisi Kesehatan: Analisis Rumah Tangga Indonesia', Jurnal Ekonomi dan Pembangunan Indonesia, 22(1), pp. 16–26. doi: 10.21002/jepi.2022.02.

ACGIH (2023) 2023 TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. Ohio: American Conference of Governmental Industrial Hygienists.

Ahmed, S. et al. (2022) 'Respiratory Symptoms, Spirometric, and Radiological Status of Stone-cutting Workers in Bangladesh: A Cross-sectional Study', Health Science Reports, 5(5), pp. 1–8. doi: 10.1002/hsr2.753.

Ajslev, J. Z. N. et al. (2022) 'The Hierarchy of Controls as an Approach to Visualize the Impact of Occupational Safety and Health Coordination', International Journal of Environmental Research and Public Health, 19(5), pp. 1–14. doi: 10.3390/ijerph19052731.

Anes, N. I., Umboh, J. M. L. and Kawatu, P. A. T. (2015) 'Faktor-Faktor Yang Berhubungan dengan Gangguan Fungsi Paru Pada Pekerja di PT.Tonasa Line Kota Bitung', Jikmu, 5(3), pp. 600–607.

Chaulya, S. K. et al. (2021) 'Fugitive Dust Emission Control Study for a Developed Smart Dry Fog System', Journal of Environmental Management, 285, pp. 1–12. doi: 10.1016/j.jenvman.2021.112116.

Darwel, D. et al. (2022) 'Descriptive Study of Respirable Dust Levels by Furniture Industry Workers in Nanggalo District, Padang City', SANITAS: Jurnal Teknologi dan Seni Kesehatan, 13(1), pp. 90–100.

Government of Indonesia (2021) Peraturan Pemerintah (PP) Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan

Lingkungan Hidup. Jakarta: Government of Indonesia.

Hardyanti, N., Huboyo, H. S. and Darmawan, M. (2021) 'Rancang Bangun Green Belt Untuk Pengendalian Pencemaran Debu di Kawasan Industri Terboyo (Jalan Kaligawe)', Jurnal Ilmu Lingkungan, 19(3), pp. 681–689. doi: 10.14710/jil.19.3.681-689.

International Labour Organization (2019) Keselamatan dan Kesehatan Kerja di Tempat Kerja. Jakarta: International Labour Organization.

Lestari, M. et al. (2023) 'Dust Exposure and Lung Function Disorders', Respiratory Science, 3(3), pp. 218–230. doi: 10.36497/respirsci.v3i3.80.

Li, H. et al. (2022) 'Effect of the Installation Angle of Nozzle on the Atomizing Performance of Air-Assisted Spraying Dust Suppression Device', Atmosphere, 13(4), pp. 1–10. doi: 10.3390/atmos13040520.

Li, S. et al. (2021) 'Review and Prospects of Surfactant-Enhanced Spray Dust Suppression: Mechanisms and Effectiveness', Process Safety and Environmental Protection, 154(6), pp. 410–424. doi: https://doi.org/10.1016/j.psep.2021.08.037.

Maleki, R. et al. (2020) 'Monitoring BTEX Compounds and Asbestos Fibers in the Ambient Air of Tehran, Iran: Seasonal Variations, Spatial Distribution, Potential Sources, and Risk Assessment', International Journal of Environmental Analytical Chemistry, 102(16), pp. 4220–4237. doi: 10.1080/03067319.2020.1781836.

Mastrantonio, R. et al. (2021) 'Exposure assessment to inhalable and respirable dust in the post — earthquake construction sites in the city of l'Aquila', Journal of Occupational Health, 63(1), pp. 1–9. doi: 10.1002/1348-9585.12296.

Ministry of Health (2012) Pedoman Analisis Risiko Kesehatan Lingkungan (ARKL). Jakarta: Direktorat Jenderal PP dan PL Kementerian Kesehatan.

National Institute for Occupational Safety and Health (2017) NIOSH Manual of Analytical Methods (NMAM). 5th Editio. Georgia: Centers for Disease Control and Prevention.

Nuhu, S. K. (2012) 'Dust Emanating From the Mineral Processing and Mining Industry: Its Effect on Human and the Environment', Continental Journal Engineering Sciences, 7(1), pp. 36–43.

President of Republic of Indonesia (2023) Undang-undang (UU) Nomor 17 Tahun 2023 tentang Kesehatan. Jakarta: President of Republic of Indonesia.

PT Freeport Indonesia (2023) Hasil Pengukuran Debu di Pabrik Pengolahan Bijih.

PT X (2022) Unpublished Report. Papua: PT. X.

Roberts, J. and Wypych, P. (2019) 'Research , Development and Application of Dust Suppression Technology', in Proceedings of the 2018 Coal Operators' Conference, Mining Engineering, pp. 319–328.

Saurabh, K. et al. (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, pp. 1037–1051. doi: https://doi.org/10.1007/s10098-020-01991-z.

Schlünssen, V. et al. (2023) 'The Prevalences and Levels of Occupational Exposure to Dusts and/or Fibres (Silica, Asbestos and Coal): A Systematic Review and Meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury', Environment International, 178(August), pp. 1–79. doi: 10.1016/j.envint.2023.107980.

Trianisa, K., Purnomo, E. P. and Kasiwi, A. N. (2020) 'Pengaruh Industri Batubara Terhadap Polusi Udara dalam Keseimbangan World Air Quality Index in India', Jurnal Sains Teknologi & Lingkungan, 6(2), pp. 156–168. doi: https://doi.org/10.29303/jstl.v6i2.154.

Wang, P., Zhang, K. and Liu, R. (2019) 'In fluence of Air Supply Pressure on Atomization Characteristics and Dust-Suppression Efficiency of Internal-mixing Air-Assisted Atomizing Nozzle', Powder Technology, 355, pp. 393–407. doi: 10.1016/j.powtec.2019.07.040.

Wang, Y. (2020) 'Overview of Downhole Spray Dust Removal Technology', in IOP Conference Series: Earth and Environmental Science, pp. 1–5. doi: 10.1088/1755-1315/558/4/042052.

Wippich, C. et al. (2020) 'Estimating Respirable Dust Exposure from Inhalable Dust Exposure', Annals of Work Exposures and Health, 64(4), pp. 430–444. doi: 10.1093/annweh/wxaa016.

Xie, Z. et al. (2022) 'Research Review and Prospect the Development of Dust Suppression Technology and Influencing Factors for Blasting Construction', Tunnelling and Underground Space Technology incorporating Trenchless Technology Research, 125(April), pp. 1–32. doi: 10.1016/j.tust.2022.104532.