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Risk Assessment of Inhalation Exposure to the Use of Chemicals in the Mineral Processing

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Abstract

Chemical exposure known as chemical hazards and toxic substances (CHTS), which occur through inhalation, ingestion, and skin contact, causes serious illness, irritation, corrosion, injury, and even death. The chemicals analyzed are limited to the reagents used in the mineral ore production process, in addition to dermal exposure. Data on hazard identification and exposure evaluation were collected. The utilization of CHTS will continue to increase in the coming years, thereby leading to health impacts on workers. Global data released by ILO showed a 270 million (62.8%) and 160 million (37.2%) rise in work accidents and illnesses, culminating in 430 million per year. Data on the number of workers who received benefits from the Work Accident Insurance program of the National Social Security Agency for Employment (known as BPJSTK), showed that 210,789 people (4,007 fatal) 221,740 people (3,410 fatal), and 234,370 people (6,552 fatal) experienced work-related accidents and illnesses in Indonesia. Therefore, this qualitative study aims to examine and analyze the health risks of mining workers exposed to CHTS through inhalation- using the observation method. The Chemical Health Risk Assessment (CHRA) method issued by the Malaysian Department of Safety and Health in 2018 was used to assess the inhalation exposure rate. The analyzed chemicals were limited to reagents used in production with data collected through the semi-quantitative method. The results showed that the inhalation exposure risk level is categorized as moderate and capable of causing health defects related to acute toxicity and specific target organ toxicity-single exposure (STOT-SE). Furthermore, 4 (four) out of 6 (six) reagents were identified as having significant inhalation exposure risk, hence, controls related to Occupational Health and Safety (OHS) in the mineral ore processing process must be increased.

Introduction

One of the key factors used by companies to promote sustainable credentials and prevent work-related illnesses is the fulfillment of Sustainable Development Goals (SDGs) (Shayan et al., 2022). In 2021/2022, over 1.8 million workers in the UK, suffered from various work-related illnesses with 722,000 new cases. Furthermore, 30.8 million days of work were lost due to these work-related illnesses with an estimated 13,000 deaths recorded each year due to major exposure to chemicals and dust (HSE, 2022). Many potential hazards pose a risk to workers' health, especially in the

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mining industry, such as exposure to chemicals through inhalation, absorption, and ingestion, which causes serious illnesses, irritation, injury, and even death (Utembe et al., 2015, Obiri et al., 2016) In 2008, a total of 2.02 million deaths related to work were recorded (Takala et al., 2014). International Labour Organization (2013) shows that annually there are more than 250 million accidents at workplaces. While 160 million workers become sick due to hazards in the workplace. Also, around 1.2 million workers die due to accidents and occupational diseases. New materials for the production process are distributed annually in the workplace, and many of them cause lung disease (Suryadi et al., 2022).

Global data released by ILO showed a 270 million (62.8%) and 160 million (37.2%) rise in work accidents and illnesses, culminating in 430 million per year. Furthermore, 2.78 million workers die yearly, with 40% of work accidents and illnesses usually among young people. The estimated economic loss of a country's GDP is 3.94 to 4%, while the associated medical costs in the United States are estimated at $67 billion, with indirect costs of approximately $183 billion (Hamalainen et al., 2017). In 2008, MSHA reported 151 cases of work-related illnesses in mines in America. These included 1 dermatitis case, 24 hearing impairment, 1 heat stroke, 60 cases of joint, tendon, inflammation, and muscle irritation, 40 cases of black lung disease (coal miner's pneumoconiosis), and 25 cases of other illnesses (Chen et al., 2013). Another report from MSHA by Scott (2009) showed that 66 chemicals obtained by operators of refining plants, ore crushers, mechanics, utility and pump workers, muck machine operators, and electrical workers are responsible for 2,705 cases of injuries and illnesses (Koh et al., 2017).

Data on the number of workers by the Indonesia Ministry of Manpower (2022) who received benefits from the Work Accident Insurance program of the National Social Security Agency for Employment (known as BPJSTK), showed that 210,789 people (4,007 fatal) 221,740 people (3,410 fatal), and 234,370 people (6,552 fatal) experienced work-related accidents and illnesses in Indonesia. The compensation costs incurred in 2019, 2020, and 2021 were Rp. 1.58T, Rp. 1.56T, and Rp. 1.79T, respectively. These data are based on the 30.66 million BPJSTK participants out of a total of 126.51 million workers in Indonesia. The above-mentioned issues and conditions are viewed as a challenge and an opportunity to adopt a new approach and innovative breakthrough. This is aimed at making work more effective in achieving progress in the field of occupational health and safety (OHS). Subsequently, this can provide a greater contribution to the success of quality, empowering, and sustainable development.

The OHS implementation requires the involvement of multidisciplinary expertise, professionals, multiple stakeholders, and the wider community for the success of a company, especially those in the mining industry. All mining industries must manage OHS risks related to the use, storage, and handling of Chemical Hazards and Toxic Substances (CHTS). The possible occurrence of various illnesses in miners is very high, hence, it is important to carry out risk assessments to minimize exposure to health hazards, especially those associated with CHTS. Several chemicals are hazardous and toxic; hence, their use can cause environmental problems and health hazards. Furthermore, CHRA is a simple and easy method that aims to enable a decision on appropriate hazardous chemical risk control actions. These include employee induction, training activities, monitoring, and health surveillance, which aims to protect the health of employees exposed to CHTS in the workplace (Taheri et al., 2019).

The risk assessment attributes in the CHRA method (Gharibi et al., 2019; Haleem, 2020) are semi-quantitative (Yari et al., 2016; Tian et al., 2018). and used due to its detailed advantages in assessing risk based on CHTS exposure routes. This process is developed to evaluate and assess health risks in each activity involving CHTS, especially those related to inhalation, dermal routes, and ingestion. These exposure routes serve as the basis for generating detailed and accurate recommendations for risk control actions, either qualitatively or quantitatively by monitoring the presence of CHTS in the air (Susanto et al., 2020). However, the CHRA method does not provide a detailed analysis of the risk assessment exposure through the ingestion routes because cases of chemical injection into the body are very rare and occur accidentally. A similar process is applied to the chemical route, which allows the injection of chemicals into the human body through a low probability of occurrence. Exposure through the injection route usually occurs due to a puncture wound caused by broken glass from glassware used as a chemical container. This assessment is not explained through the CHRA method. Based on the description above, this study was conducted to assess the health risks of CHTS used to process mineral ores. The exposure assessment was specifically for the inhalation route carried out using the CHRA method for Production Department workers at the Concentrating Division of Freeport Indonesia Company (PTFI). The health risk assessment is carried out according to the CHTS characteristics by taking into account the amount used.

Method

This is a qualitative study, using the observation method with primary data sourced through interviews, observation, SOPs evaluation, and Safety Data Sheets (SDSs). Additionally, secondary data were obtained by cross-checking information on chemical hazards stored on the website of the European Chemicals Agency (ECHA) or the ASEAN-Japan Chemical Safety Database (AJCSD). This subject study population comprises seven CHTS, commonly referred to as reagents, used by the Production Department in the Concentrating Division of PT Freeport Indonesia in 2023. Based on the population size, the saturation method was used in the production process as a reagent. A semi-quantitative method was used to assess the health risks based on the CHRA method, with the exposure assessment limited to the inhalation route (DOSH, 2018). This method consists of several processes with a systematic approach used to identify the hazards, managerial processes, effectiveness of the implemented control, and the risk level at the workplace. The flowchart of this study is shown in Figure 1.

Data were collected from the SOP applied in the Production Department of the Concentrating Division of PTFI to determine the methods, CHTS profile, health impact, duration, frequency, level of release, conditions of activities, as well as the area of contact through the inhalation exposure route. The CHTS hazard profile data obtained from ECHA, AJCSD, and SDS were used to determine the worker's hazard classification, H-code, acute toxicity, and health effects. Additionally, data on duration and frequency of work were obtained from interviews and observations conducted on workers as well as interview sheets. The data obtained for each CHTS were evaluated and entered into the tool used in CHRA and evaluated to determine the inhalation risk level.

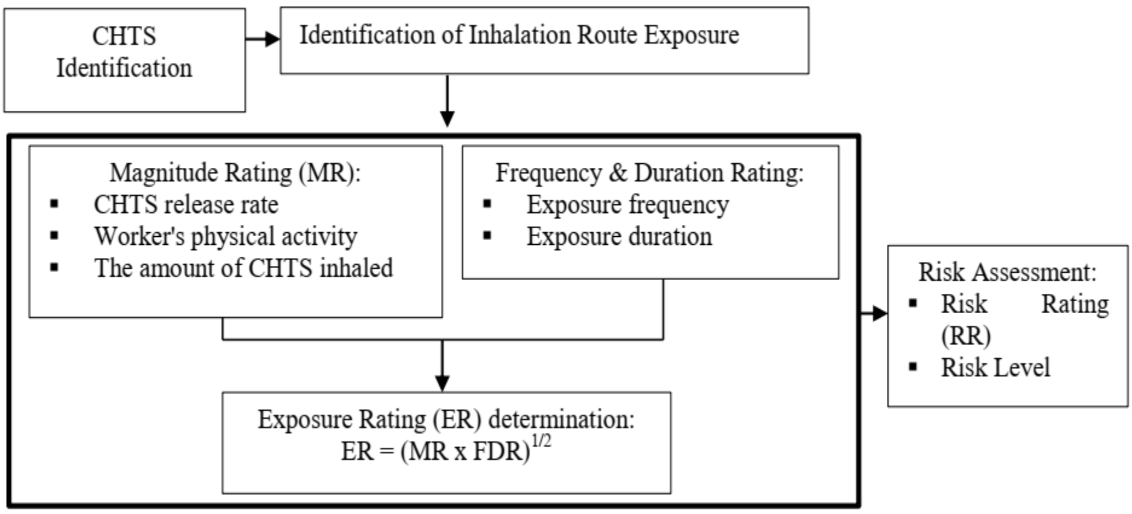

Figure 1. Flow chart of inhalation exposure risk assessment by CHTS.

Chemical hazards present in the workplace are identified by surveys and understanding business process flows. The hazard level is determined using the hazard, acute toxicity, and health effect classifications of CHTS. Furthermore, inhalation exposure uses a Hazard Rating (HR) with a scale level of 1 to 5, as shown in Table 1. The ranking implies the least to the most severe adverse health impact, with CHTS information obtained from SDS for each reagent assessed to determine HR. Table 1 shows the HR for inhalation exposure with the highest hazard assessed using CHTS. This inhalation route hazard categorization is based on the Globally Harmonized System of Chemicals Classification and Labeling (United Nations, 2021).

Table 1. Hazard Rating (HR)

HR	Hazard Classification	H-code
5	Acute toxicity category 1 (inhalation)	H330
	Carcinogenicity category 1A	H350, H350i
	Mutagenicity category 1A	H340
	Reproductive toxicity category 1A	H360, H360D, H360F, H360FD, H360Fd, H360Df
	Specific target organ toxicity (STOT): single exposure (SE) category 1	H370
4	Acute toxicity category 2 (inhalation)	H330
	Carcinogenicity category 1B	H350, H350i
	Mutagenicity category 1B	H340
	Reproductive toxicity category 1B	H360, H360D, H360F, H360FD, H360Fd, H360Df
	Effects on or via lactation	H362
	Specific target organ toxicity (STOT): single exposure (SE) category 2	H371
	Specific target organ toxicity (STOT): repeated exposure (RE) category 1	H372
	Respiratory sensitization category 1	H334
3	Acute toxicity category 3 (inhalation)	H331
	Carcinogenicity category 2	H351
	Mutagenicity category 2	H341
	Reproductive toxicity category 2	H361, H361f, H361d, H361fd
	Specific target organ toxicity (STOT): repeated exposure (RE) category 2	H373
	Specific target organ toxicity (STOT): single exposure (SE) category 3 (Respiratory tract irritation)	H335
2	Acute toxicity category 4 (inhalation)	H332
	Specific target organ toxicity – single exposure category 3 (narcotic effect)	H336
1	Chemicals not otherwise classified	H333

Source: DOSH, 2018.

Exposure evaluation through the inhalation route is carried out to obtain ER, which is a function of FDR and MR. FDR is obtained by plotting FR against DR as shown in Table 2 and after it is reduced, MR ranking is assessed. MR is determined by measuring the physical and chemical properties of the material and human interaction during CHTS handling as shown in Table 3. Next, the MR conversion factor is used to determine the criteria as shown in Table 4, with ER obtained by plotting FDR and MR as illustrated in Table 5. The risk level of inhalation exposure is based on RR derived from HR and ER as illustrated in Table 5.

Table 2. Rating Determination for Frequency and Duration

Frequency		Duration per shift(s)	Rating
Frequent	Exposure once or more per shift or per day	x ≥ 7 hours	**5**
Probable	Exposure more than once per week	4 ≤ x < 7 hours	**4**
Occasional	Exposure greater than once per month	2 ≤ x < 4 hours	**3**
Remote	Exposure greater than once per year	1 ≤ x < 2 hours	**2**
Improbable	Exposure once per year or less	x < 1 hour	**1**

Frequency-Duration Rating (FDR)

		Frequency Rating (FR)				
	1	**2**	**3**	**4**	**5**	
Duration Rating (DR)	**1**	1	2	2	2	3
	2	2	2	3	3	4
	3	2	3	3	4	4
	4	2	3	4	4	5
	5	3	4	4	5	5

Source: DOSH, 2018.

The first step in determining the risk level in inhalation exposure is to calculate the RR value, using the following formula:

RR inhalation = HR x ER (1)

Table 3. Degree of Chemical Release or Presence

Degree	Observation
Low	• Low or little release into the air. • No contamination of air, clothing, and work surfaces with chemicals. • Low volatility with a boiling point of more than 150°C at room temperature (20°C). • Low dustiness such as pellet-like solids that don't break up. Little dust is seen during use e.g. PVC pellets, waxed flake
Moderate	• Moderate release such as: a) Solvents with medium drying time in uncovered containers or exposed to the work environment; b) Detectable odour of chemicals. Check the odour threshold. • Medium volatility with the boiling point at 50 to 150°C in the room temperature (20°C). • Medium dustiness such as crystalline, granular solids. When used, dust is seen, but settles out quickly. Dust is left on surfaces after use e.g. soap powder. • Evidence of contamination of air, clothing, and work surfaces with chemicals.
High	• Substantial release such as: a) Solvents with fast drying time* in uncovered containers; b) Sprays or dust clouds in poorly ventilated areas; c) Chemicals with high rates of evaporation exposed to work environment; d) Detectable odour of chemicals with odour threshold at/above PEL/OEL. • High volatility with a boiling point of less than 50°C at room temperature (20°C). • High dustiness such as fine, light powders. When used, dust clouds can be seen to form and remain in the air for several minutes e.g. cement, carbon black, and chalk dust. • Gross contamination of air, clothing, and work surfaces with chemicals.

Degree of Chemical Inhaled and Physical Activities

Physical Activity	Observation/ Condition	Breathing Rate
Light Work • Sitting, moderate arm and trunk movements (e.g. desk work, typing) • Sitting, moderate arm and leg movements(e.g. hand soldering and QC inspection) • Standing, light work at machine or bench, mostly arms	• Low breathing rate (light work) • Source far from the breathing zone	**Low**
Moderate Work • Sitting, heavy arms and legs movement • Standing, light work at machine or bench, some walking about • Standing, moderate work at machine or bench, some walking about • Walking about, with moderate lifting or pushing (e.g. machine operator)	• Moderate breathing rate (moderate work) • Source close to the breathing zone	**Medium**
Heavy Work • Intermittent heavy lifting, pushing or pulling(e.g. pick and shovel work) • Hardest sustained work	• High breathing rate (heavy work) • Source within the breathing zone	**High**

Magnitude Rating (MR) Determination

		Degree of Inhaled		
		Low	**Moderate**	**High**
Degree of Release (presence)	**Low**	1	2	3
	Moderate	2	3	4
	High	3	4	5

Table 4. Modifying Factors

MR modifying factor	Criteria for modifying factors
+ 1 (maximum MR not to exceed 5)	• Bad work practice and or poor personal hygiene that may have the potential for the chemical agents to remain on skin or clothing, once contact occurs. • Reported cases of chemical exposure incidences. The results of biological monitoring exceed the Biological Exposure Index (BEI) (such as those described by the ACGIH). • Widespread complaints of ill effects related to exposure to the CHTH, in the work unit. • Reported cases of workers with pre-clinical symptoms related to the CHTH exposure. • Susceptible persons in the work unit. • Cross airborne contamination
-1 (minimum MR not less than 1)	• Quantity used is small for solid (weight in grams or typically received in packets or bottles) and for liquid (volume in milliliters or typically received in bottles)

Source: DOSH, 2018.

Table 5. Exposure Rating (ER) Determination

		Magnitude Rating				
		1	**2**	**3**	**4**	**5**
Frequency-Duration Rating (FDR)	**1**	1	2	2	2	3
	2	2	2	3	3	4
	3	2	3	3	4	4
	4	2	3	4	4	5
	5	3	4	4	5	5

Level of Risk

Level of Risk	**Risk Rating Value**
Low risk	1 – 4
Moderate risk	5 – 12
High risk	15 – 24

Source: DOSH, 2018.

Table 6. Hazard Rating and Exposure Rating Determination for Inhalation Exposure

CHTS	Composition	Hazard Classification	Hazard Category	H-Code	Hazard Rating
AERO® 7249 Promoter	Dithiophosphate, Monothiophosphate, 2-methylpropane-1-ol	STOT-SE	3	H335 H336	3
AERO® 317 Xanthate	Xanthate, 2-methylpropan-1-ol, Carbonic acid, Disodium salt, Disodium sulfide	Acute toxicity STOT-SE Acute toxicity	4 3 3	H312 H335, H336 H301	3
OREPREP® OTX-140PTFI Frother	Alcohols, glycols, glycols ethers	N/A	N/A	N/A	N/A
Rheomax DR1050	Polyacrylamide, anionic	N/A	N/A	N/A	N/A
Solutrix 11	Phosphonic acid, (nitrilotris(methylene))tris, 2-methyl-2H-isothiazol-3-one	Acute toxicity Acute toxicity	2 3	H330 H311	4
Lime	Calcium oxide	STOT-SE	3	H335	3

N/A: not applicable

CHTS	Exposure Rating									
	HR	**Frequency-Duration Rating**			**Boiling Point (°C)**	**Magnitude Rating**			**ER**	**RR**
		FR	**DR**	**FDR**		**Degree of Release**	**Degree of Inhaled**	**MR**		
AERO® 7249 Promoter	3	5	2	4	N/A	Low	Moderate	2	3	9
AERO® 317 Xanthate	3	5	2	4	N/A	Moderate	Moderate	3	4	12
Solutrix 11	4	5	2	4	180	Low	Moderate	2	3	12
Lime	3	5	2	4	2850	Low	Moderate	2	3	9

Source: elaborated by the authors based on research, 2023.

The flotation process produces copper-gold concentrate from crushed ore which exposes the workers to most chemicals. The concentrate slurry consisting of fine-crushed ore and water mixed with reagents is entered into a mixing tank known as the flotation cell, where the air is also pumped into the slurry. The chemicals used are collectors, frothers, and lime with their HR and hazardous properties shown in Table 6. This inhalation exposure assessment is performed semi-quantitatively based on the process of determining FDR, MR, and ER. This table shows the assessment results of chemicals related to inhalation exposure.

The Concentrating Division of PTFI involves the use of chemicals as reagents in the flotation process, which is an important technique used to separate minerals to produce copper and gold concentrates. The concentrate slurry consisting of fine ore and water mixed with reagents is introduced into a series of stirring tanks (flotation cells) using various reagents, such as lime, frothers, collectors, and depressants. Continuous pulp flotation produces toxic compounds such as carbon disulfide (CS2), which can accumulate in the flotation plant. This condition poses significant dangers to safety, health, and the environment (Shen et al., 2016; Bararunyeretse et al., 2017). Risk assessment is essential to minimizing CHTS exposure, thereby reducing the potential for accidents and diseases.

Table 6 shows the HR, ER, and RR values for each chemical related to inhalation exposure. The risk level is determined based on the RR value, which takes into account the amount of AERO® 317 Xanthate or Sodium Isobutyl Xanthate (SIBX) used in the form of pellets. Direct exposure to SIBX occurs during the process of transferring SIBX from the bags to the tank for mixing with water. This process is carried out three to five times a week using four SIBX bags weighing 850 kg each. Direct exposure also occurs during the tank cleaning process carried out once a month, using OREPREP® OTX-140PTFI Frother in liquid form. This reagent used is approximately 18-20 tons with valve opening activities and direct exposure carried out once a month during the flow inspection procedure. The final result for inhalation exposure shows that all chemicals related to inhalation hazards are categorized as high risk for AERO® 317 Xanthate and medium risk for OREPREP® OTX-140PTFI Frother and lime.

Reagents in mineral processing are very necessary and inseparable parts of the flotation process. Some reagents such as collectors, frothers, surface modifiers, activators, pH regulators, and depressants control the physical and chemical conditions of the solid, air, and liquid phases while maximizing the recovery of all metals. Besides being efficient in production, reagents also have potential hazards that can harm the health of workers (Bararunyeretse et al., 2017). Based on the results, all chemicals related to inhalation hazard exposure, namely AERO® 317 Xanthate, OREPREP® OTX-140PTFI frothers, and limestone are categorized as moderate-risk irritants. Therefore, if the workers' bodies come into contact with an irritant, they inflame and become red. Inflammation is one of the body's defense mechanisms characterized by the narrowing of small blood vessels in the affected area, dilation, rise in permeability, migration of white blood cells, and others hazardous to the chemical.

The most common route of chemical entry into the body is the inhalation of toxic gases, vapors from volatile substances, and particulates through the respiratory system, which cause occupational lung disease (Andarini et al., 2019). The main location of absorption is the alveoli, which are found in the lungs (Patnaik, 2007). Chemicals in the lungs or other organs can affect this system directly through the blood, lymph, or phagocytic cells after absorption. The type and severity of the toxic impact depend on the properties of the substance, the amount absorbed, the absorption rate, the individual's vulnerability, etc. Furthermore, some chemicals, such as beryllium, thorium, silica, asbestos, and toluene-2,4-diisocyanate cannot be absorbed due to their difficulty in dissolving in the blood. According to the National Research Council in 2000, chemicals that are not easily soluble, remain in the lungs for years when inhaled, thereby causing irritation, inflammation, fibrosis, aggressive cell growth, and allergic sensitization.

The respiratory system is the main target of easily soluble chemicals, such as chlorine or phosgene, vapor, gas, and mist, which attack the upper respiratory tract. Less soluble gases, such as nitrogen oxides, penetrate deeper into the channels between the nasal cavity and the terminal bronchiole of the airways. In some cases, this process causes lung edema, which often occurs after a time interval. Other parts of the body that are susceptible to material in the air, such as splashes, mouth, and pharynx from the swallowing process of irritants in liquid or solid form are the skin and eyes. Inhalation exposure to xanthates irritates the respiratory system, thereby leading to drowsiness, dizziness, anaesthesia, decreased alertness, loss of reflexes, lack of coordination, and vertigo. Xanthates also hydrolyze in water solutions and pulp flotation to produce CS2, which accumulates in flotation plants and presents a significant hazard. Toxic anaesthetic and narcotic chemical reagents act as depressants on the central nervous system. Chemical substances that are included in anaesthetics and narcotics are hydrocarbons with their derivative compounds consisting of various chlorine or ether-based solvents. Xanthatea is a carbonate acid product, in which two oxygen atoms and an alkyl group are replaced by sulfur and one hydrogen atom, respectively. Xanthates hydrolyze and form unstable xanthic acid, which then decomposes into the appropriate carbon disulfide and alcohol (Shen et al., 2016).

Exposure to liquid carbon disulfide causes eye, skin, and respiratory tract irritations with acute poisoning effects, such as tremors, dyspnea, cyanosis, and collapse of blood vessels. Furthermore, exposure to carbon disulfide at an acute level or concentrations up to 500-1000 ppm, cause psychosis and anaesthesia. Long-term exposure is also responsible for nerve system effects including fatigue, insomnia, headaches, and irritability, increased susceptibility to heart disease including heart attack, high blood pressure, angina, eye damage, reproductive defects, and hearing disorders. Frothers are active heteropolar surface organic surfactants that contain polar groups of OH, COOH, CO, OSO2, and SO2OH, as well as hydrocarbon radicals, adsorbed at the air-water interface. The health classification related to inhalation hazards for frothers involves reproductive toxicity and single target organ toxicity (STOT-SE). Lime (calcium oxide-CaO or calcium hydroxide (Ca (OH)2) is an effective and economical pH modifier widely used in the selective flotation of primary sulfide minerals. The health hazard classification related to its inhalation hazards is STOT-SE. Systemic poisoning attacks critical organs, such as the kidneys, liver, blood, and bone marrow. This is because inhaled toxins are sometimes deposited in the bronchioles and alveoli in the lungs belonging to the respiratory fibrogenic type. Furthermore, the chemical has a specific particle size and shape of 0.5 to 0.7μm in the form of dust, such as silica or various types of asbestos, which enter and accumulates in the bronchioles thereby causing the lungs to lose elasticity.

Conclusion

In conclusion, the assessment of inhalation exposure conducted in this study was obtained through surveys on relevant work, processes, and determinants in the workplace. The results showed that the inhalation exposure risk level is categorized as moderate and capable of causing health defects related to acute toxicity and specific target organ toxicity-singe exposure (STOT-SE). Furthermore, 4 (four) out of 6 (six) reagents were identified as having significant inhalation exposure risk, Reagents used in mineral processing in the mining industry are large-scale and capable of causing significant CHTS exposure risks, especially through inhaling. The activities and work environment carried out by workers are acceptable because they are controlled by environmental monitoring. However, control measures should be applied to maintain OHS while minimizing its exposure.

Some recommendations for control measures can be carried out according to the control hierarchy. The first control is conducting the engineering process, which involves modifying hoppers in tanks combined with automatic bag-cutting machines. The cutting machine is designed to hinder workers from direct exposure to reagent dust when cutting packaging bags. The next is administration control, which is used to implement training, including hazard communication, training, and GHS reagent symbols. Another administrative control includes ensuring that work is always carried out by SOP after mixing and using the reagent with the minimum amount in the storage area. The last control hierarchy is the use of Personal Protective Equipment (PPE), which is essential in minimizing exposure. PPE comprising a respirator, safety glasses, coveralls, gloves, safety shoes, and a suitable safety helmet should be worn and ensured before and during work. When necessary, additional PPE such as a hair net can be used before using the helmet.

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