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CHEMICAL HEALTH RISK ASSESSMENT IN THE METALLURGY DEPARTMENT OF A MINING COMPANY, INDONESIA : A CASE STUDY

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ABSTRACT

Background: Miners are routinely exposed to various hazardous chemicals entering the body through inhalation, dermal, and ingestion. Although, likely, the long-term health impacts of certain chemicals will only become evident in years to come, the utilization of hazardous chemicals will continue to increase in the coming years, leading to a higher disease burden. Therefore, effective controls for the sound management of chemicals at the workplace shall be implemented. **Purpose**: This study aimed to assess the chemicals used and analyze the health risks related to the use of the chemicals in the flotation process. **Methods**: This study was a descriptive case study conducted in Indonesia's gold and copper mining company. We ran the assessment using the Chemical Health Risk Assessment method published by the Department of Safety and Health, Malaysia, Year 2018. The chemicals analyzed were limited to the reagents used in the flotation process in the metallurgy department, which have two possible exposure, inhalation, and dermal routes. **Results**: The results show three out of seven chemicals have the potential to expose workers through inhalation, which is categorized under medium risk, where xanthate has the highest risk rating (RR=12), which potentially causes health effects related to acute toxicity, specific target organs, and reproductive toxicity. Meanwhile, five out of seven chemicals have the potential to expose workers through dermal, where three chemicals fell into the high-risk category: promoter, frother, and lime (H2), and two chemicals fell into the moderate-risk category: xanthate and solutrix (M2). Adverse health effects from chemical exposures to dermal include irritation, corrosion, and sensitization. **Conclusion**: The reagents used in the flotation plant exhibited a significant health risk of inhalation and dermal contact with hazardous chemical exposure. The company shall evaluate the hazard and risk from the hazardous chemicals used in the flotation plant and implement adequate controls, considering elimination, substitution, engineering, administrative, and personal protective equipment (PPE) controls to minimize the workers' inhalation and dermal exposure.

Keywords: chemical health risk assessment; dermal; inhalation; mining, reagents

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INTRODUCTION

Many mining industry hazards can pose risks to workers' health. Miners are routinely exposed to various chemical hazards, which can enter the body by being inhaled into the lung, absorbed through the skin, or ingested through the mouth. The chemical hazards can cause serious illness, irritation, injury, or even death (NSW Government, no date; Donoghue, 2004; Scott *et al*., 2009; Utembe *et al*., 2015; Obiri *et al*., 2016). Work-related diseases carry a significant mortality burden. According to the International Labor Organization (ILO), in 2008, work-related diseases killed 2.02 million people, and work-related accidents killed 321,000 people (International Labour Organization (ILO), 2011; Takala *et al*., 2014). Therefore, concerning the strategy for preventing occupational ill health, the ILO has referred to a new prevention paradigm, focusing on occupational diseases and not only occupational injuries (Harrison *et al*., 2016). The underlying causes of work-related diseases may be complex, and certain workplace exposures are known to contribute to the progression of a disease, including dangerous substances (EU-OSHA, 2023).

Flotation is a crucial technique in the mineral processing industry that involves chemicals to separate minerals. The flotation technique works with reagents such as collectors, frothers, and depressants (Langa *et al*., 2014). Some reagents contain hazardous chemicals which generate environmental concerns and health hazards. Flotation pulp constantly produces toxic compounds such as carbon disulfide (CS2). These compounds accumulate in flotation plants and pose significant safety, health, and environmental risks (Shen *et al*., 2016; Bararunyeretse *et al*., 2017).

Previous estimates published by the ILO have found that over 2,780,000 workers die globally each year due to their working conditions and that exposure to hazardous substances claims the lives of almost 1 million workers. In other words, at least one worker dies every 30 seconds due to occupational chemical exposure. Likely, the long-term health impacts of certain chemicals will only become evident in years to come. However, the utilization of hazardous chemicals in industrial processes will continue to increase in the coming years, even leading to a higher burden of disease (ILO, 2021).

Taking all these into account, effective controls for the sound management of chemicals at the workplace shall be implemented (International Council on Mining and Metals, 2016, ILO, 2021). Therefore, this study was conducted to objectively evaluate the chemicals used and analyze the health risks associated with the use of chemicals in an Indonesian gold and copper mining company as publications of such risks in the gold and copper mining from this country are lacking. Chemical health risk assessment (CHRA) is conducted considering the characteristic and the amount of the chemicals used, which is generally substantial in the mining industry.

METHOD

Study Design and Area

This study was a descriptive case study, enabling the researcher to closely examine the health risks due to chemical exposure within a specific location. It was conducted in The Metallurgy Department of Indonesia's gold and copper mining company in 2019.

Tools

The Chemical Health Risk Assessment (CHRA) of this study used the Malaysian Ministry of Occupational Safety and Health (DOSH) "Assessment of Health Risks resulting from the Use of Hazardous Chemicals in the Workplace" methodology (Department of Occupational Safety and Health Malaysia (DOSH), 2018). The evaluated chemicals in this study were limited to two routes of exposure, namely inhalation, and dermal route. CHRA consists of several processes that use a systematic approach to identifying hazards, processes for the use and control of hazardous chemicals. The risk levels in the workplace and the effectiveness of the implemented controls. The assessments are derived from observations and interviews in the workplace.

Recognition and Determination of the Degree of Hazard

The chemical hazards that exist in the workplace were identified by a walkthrough survey and understanding of the business process flow. Hazard levels are determined based on hazard classification, acute toxicity, and the health effects of chemicals that are harmful to health. Inhalation exposure uses a hazard rating (HR), and dermal exposure uses the chemical's specific hazardous properties to indicate the degree of hazard. The scale of HR is 1 to 5. A rating of 1 means the least adverse health effects, and a rating of 5 means the most severe health effects. Chemical hazard information was obtained from the Safety Data Sheet (SDS) for each chemical assessed to determine the HR and hazard properties. The HR for inhalation is shown in Table 1. We listed the HR assigned and selected the highest HR to determine the hazard level for the evaluated chemicals.

Table 1. Hazard Rating for Inhalation Exposure
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

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 – single exposure 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 – single exposure category 2	H371
	Specific target organ toxicity – repeated exposure 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 – repeated exposure category 2	H373
	Specific target organ toxicity – single exposure 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	Chemical not otherwise classified	H333

The degree of hazard for dermal exposure is categorized by its effects on the skin and eyes and is further divided by its specific hazardous properties, such as irritation, corrosion, sensitization, acute toxicity, and skin absorption. The hazardous properties of dermal exposure are outlined in Table 2. The inhalation and dermal contact hazards classification follow the chemical hazard classification in the Globally Harmonized System of Classification and Labeling of Chemicals (Nations, 2017).

Table 2. Hazardous Properties Relevant to Dermal Exposure
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

Hazardous properties	Corresponding hazard classification and H-code
Irritation	• Skin corrosion or irritation category 2 (H315) • Serious eye damage or eye irritation category 2 (H319)
Corrosion	• Skin corrosion or irritation category 1 (H314) • Serious eye damage or eye irritation category 1 (H318)
Sensitization	• Skin sensitization category 1 (H317)
Acute toxicity	• Acute toxicity (dermal) category 1 (H310) • Acute toxicity (dermal) category 2 (H310) • Acute toxicity (dermal) category 3 (H311) • Acute toxicity (dermal) category 4 (H312)
Skin-absorption and other properties	• Specific target organ toxicity-single exposure category 1* (H370) • Specific target organ toxicity-single exposure category 2* (H371) • Specific target organ toxicity-repeated exposure category 1* (H372) • Specific target organ toxicity-repeated exposure category 2* (H373) • Carcinogenicity category 1*(H350) • Carcinogenicity category 2*(H351) • Germ cell mutagenicity category 1*(H340) • Germ cell mutagenicity category 2*(H341) • Reproductive toxicity category 1*(H360, H360D, H360F, H360FD, H360Fd, H360Df) • Reproductive toxicity category 2*(H361, H361f, H361d, H361fd)

Exposure Evaluation

The exposure evaluation through inhalation was carried out using a semi-quantitative method, while dermal exposure evaluation was assessed using a qualitative methodology. Inhalation Exposure Rating (ER) was evaluated as a function of frequency and duration rating (FDR) and magnitude rating (MR). The FDR was derived by plotting the frequency rating (FR) and duration rating (DR) shown in Tables 3 and Table 4.

Table 3. Rating Determination for Frequency and Duration
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

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

Table 4. Frequency-Duration Rating
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018).

		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

After deriving the FDR, we evaluate the magnitude assessment (MR), which is determined by measuring the physicochemical properties of the material and human interactions during chemical handling. In other words, MR is evaluated by estimating the levels of released and inhaled chemicals, as shown in Tables 5, 6, and 7.

Table 5. Degree of Chemical Release or PresenceSource: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

Continuation of Table Table 5. Degree of Chemical Release or PresenceSource: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

Degree	Observation
Low	• Low or little release into the air. • No contamination of air, clothing and work surfaces with chemicals. • Low volatility with the boiling point more than 150oC at room temperature (20oC). ** • 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 work environment; b) Detectable odour of chemicals. Check the odour threshold. • Medium volatility with the boiling point at 50oC to 150oC at room temperature (20oC). ** • 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 the boiling point less than 50oC at room temperature (20oC). ** • 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, chalk dust. • Gross contamination of air, clothing and work surfaces with chemicals.

Table 6. Degree of Chemical Inhaled and Physical Activities
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

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 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 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 breathing zone	High

Table 7. Magnitude Rating Determination
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

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

Use MR modifying factor if applicable (Table 8). Then we get an exposure rating (ER) by plotting FDR and MR Table 9. A qualitative evaluation of exposure through the dermal route was performed by determining the extent and duration of dermal contact. The extent of dermal contact determination is presented in Table 10, and the duration of dermal contact is estimated by the following duration categories, short term (<15 minutes/shift) and long term (≥15 minutes/shift).

Table 8. Modifying Factors
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

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 potentials for the chemical agents to remain on skin or clothing once contact occurs. • Reported cases of chemical exposure incidences. 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 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 milli liters or typically received in bottles)

Table 9. Exposure Rating (ER) Determination
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

		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

Table 10. Extent of Dermal Contact
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018)

Extent of Contact	Observation/Condition
Small	• Small-area of contact with chemicals capable of skin absorption, skin sensitizing or causing damage to the dermal e.g. limited to palm (intact skin) (< 2% or 0.04 m^2); • No indication of any skin conditions; intact/normal skin; • No contamination of skin or eyes.
Large	• Contact with chemicals capable of skin absorption, skin sensitizing or causing damage to the dermal; • Gross contamination with chemicals capable of skin absorption, skin sensitizing or causing damage to the dermal – skin soaked or immersed in chemicals; • Area of contact not only confined to hands but also other parts of body. Skin area >2%; • Follicle rich areas; • Skin dryness or detectable skin conditions (e.g. peeling, cracking, skin redness)

Level of Risk Determination

The risk level of inhalation exposure was based on the risk rating (RR) derived from HR and ER shown in Table 11. RR is the risk rating (1 to 25), indicating the likelihood of illness. HR is the hazard rating (1 to 5), indicating the severity of adverse effects, and ER is the exposure rating (1 to 5), indicating the chance of overexposure to the chemicals. The risk level of dermal exposure, shown in Table 12, categorized into three categories of risk which are low risk (L), moderate risk (M1 & M2), and high risk (H1 & H2). The highest level of risk will be selected when there is more than one hazardous property by dermal in a chemical.

Table 11. Level of Risk for Inhalation Exposure
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018

		Exposure Rating (ER)				
		1	2	3	4	5
Hazard Rating (HR)	1	RR=1	RR=2	RR=3	RR=4	RR=5
	2	RR=2	RR=4	RR=6	RR=8	RR=10
	3	RR=3	RR=6	RR=9	RR=12	RR=15
	4	RR=4	RR=8	RR=12	RR=16	RR=20
	5	RR=5	RR=10	RR=15	RR=20	RR=25

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

Table 12. Risk Matrix for Dermal Exposure
Source: (Department of Occupational Safety and Health Malaysia (DOSH), 2018).

Hazardous Properties	Relevant H-Code	Duration/ Extent of Skin Contact			
		Short-Term (< 15 m)		Long-Term (≥ 15 m)	
		Small Area	Large Area	Small Area	Large Area
Irritation	H315	L	M1	M1	M2
	H319	M1		M2	
Corrosion	H314	M1	H1	H1	H2
	H318	H1		H2	
Sensitisation	H317	L	M1	M1	H1
Acute Toxicity	H312	M1	M1	M2	H1
	H311	M1	M1	M1	H1
	H310	H1	H1	H1	H2
Combination Effect*	H310 with H314	H1	H1	H1	H2
Skin absorption and other properties**	H351	M1	M1	M2	H1
	H350	H1	H1	H1	H2
	H341	M1	M1	M2	H1
	H340	H1	H1	H1	H2
	H361, H2361f, H361d, H361fd	M1	M1	M2	H1
	H360, H360F, H360D, H360FD, H360Fd, H360fD	H1	H1	H1	H2
	H370	H1	H1	H1	H2
	H371	M1	M2	M2	H1
	H372	M1	M1	M2	H1
	H373	L	M1	M2	M2

L = Low Risk **M = Moderate Risk** **H = High Risk**

Note: *For chemicals classified both as acute toxicity (dermal) category 1 or 2 and skin corrosion or irritation category 1 (1A/1B/1C); **If indicate as skin absorption or effect is due to dermal exposure.

RESULTS

The mill generates gold and copper concentrates from mined ores by separating valuable minerals from the impurities. The main steps of the process are crushing, grinding, flotation and dewatering. Resizing ore into fine particles to release copper and gold elements is completed in the final crushing and grinding steps. Flotation is the process that produces copper-gold concentrate from crushed ore, which is the step where workers incur the most chemical exposure. Concentrate slurry inclusive of finely ground ore and water combined with reagents is added into mixing tanks called flotation cells, wherein the air is likewise pumped into the slurry. The evaluated chemicals are collector, frothers, and lime. Table 13 shows the results for determining the HR and hazardous properties of the chemicals used in the mill.

Table 13. Hazard Rating and Hazardous Properties Determination for Inhalation and Dermal Exposure

Name of Chemical	Composition	Health Hazard Classification	Hazard Category	H-Code	Degree of Hazard: Inhalation (Hazard Rating)	Degree of Hazard: Dermal (Hazardous Properties)
Magnafloc	(2-Propen-1-aminium, N,N-dimethyl-N-2-propenyl-, chloride, homopolyme)	**NA** (*only for environmental hazard*)				
AERO Xanthate	Xanthate, 1-Propanol, 2-methyl-, Sodium carbonate, Sodium sulfide	Acute Toxicity Acute Toxicity Acute Toxicity Skin Corrosion/ Irritation Eye Irritation STOT SE	Category 4 Category 5 Category 5 Category 2 Category 2 Category 3	H302 H313 H333 H315 H319 H335	**3**	Irritation
AERO 7249 Promoter	Dithiophosphate	Skin Irritation Serious Eye Damage	Category 2 Category 1	H315 H318	**NA**	Irritation, corrosion
OREPREP OTX-140 Frother	Aliphatic alcohol, 2-Ethylhexan-1-ol, 2-Ethylhexanal, 1-butanol	Acute Toxicity Skin Irritation Serious Eye Damage Skin Sensitization	Category 4 Category 2 Category 1 Category 1	H302 H315 H318 H317	**3**	Irritation, corrosion, sensitization

Continuation of Table 13. Hazard Rating and Hazardous Properties Determination for Inhalation and Dermal Exposure

Name of Chemical	Composition	Health Hazard Classification	Hazard Category	H-Code	Degree of Hazard: Inhalation (Hazard Rating)	Degree of Hazard: Dermal (Hazardous Properties)
		Reproductive Toxicity STOT SE	Category 2 Category 3	H361d H335		
Rheomax DR 1050	polyacrylamide			**NA**		
Solutrix 11		Skin Irritation Serious Eye damage	Category 2 Category 2A	H315 H319	**NA**	Irritation
Lime		Serious Eye damage Skin Irritation STOT-SE	Category 1 Category 2 Category 3	H318 H315 H335	**3**	Corrosion, irritation

The inhalation exposure assessment was conducted semi-quantitatively by referring to FDR, MR, and ER determination. Table 14 shows the assessment results of the chemicals related to inhalation exposure. The HR, ER, and RR values for each chemical substance associated with inhalation exposure are shown. The risk level is determined using an RR value considering the number of chemicals used. AERO 317 xanthate or sodium isobutyl xanthate (SIBX) is used on a massive pellet form scale. Direct exposure to SIBX occurs during moving SIBX from the delivered bags to the tank to be mixed with water. The mixing process is done three to five times a week. Each mixing process uses four bags of SIBX weighing 850kgs per bag. Direct exposure also occurs in the tank cleaning up process, conducted once per month. OREPREP OTX-140 Frother is also used on a massive scale in liquid form. These reagents are used in approximately 18-20 tons for valve opening activities. Direct exposure to these reagents occurs in flow checking procedures conducted around once a month. The final results for inhalation exposure show that all of the chemicals related to inhalation hazards are categorized as medium risk.

Table 14. Chemical Health Risk Assessment for Inhalation Exposure

Name of Chemical	HR	Frequency-Duration Rating: FR	DR	FDR	Boiling Point (°C)	Magnitude Rating: Degree of Release	Degree of Inhaled	MR	ER	RR
AERO 317 Xanthate	3	5	2	4	NA	Moderate	Moderate	3	4	**12**
OREPREP OTX-140 Frother	3	5	2	4	180	Low	Moderate	2	3	**9**
Lime	3	5	2	4	2850	Low	Moderate	2	3	**9**

Table 15 shows the measured assessment of dermal exposure. Based on observations and interviews in the metallurgy production, we determined that all chemicals fall into the small area skin contact category, which indicates that direct contact is limited only to the palm (<2% or 0.04 m^2). It was also found to be under the long-term duration category (≥ 15 minutes/shift). The final results for dermal assessment show that three chemicals are categorized under high risk: AERO 7249 Promoter, OREPREP OTX-140 Frother, and lime. Two chemicals are categorized under moderate risk, namely AERO Xanthate and Solutrix.

Table 15. Chemical Health Risk Assessment for Dermal Exposure

Name of Chemical	Hazardous Properties	Exposure		Risk Rating	Level of Risk
		Extent of Dermal Contact	Duration of Dermal Contact		
AERO Xanthate	Irritation	Small	Long Term	M2	**Moderate**
AERO 7249 Promoter	Irritation Corrosion	Small	Long Term	M2 H2	**High**
OREPREP OTX-140 Frother	Irritation Corrosion Sensitization	Small	Long Term	M2 H2 H1	**High**
Solutrix 11	Irritation	Small	Long Term	M1 M2	**Moderate**
Lime	Corrosion Irritation	Small	Long Term	H2 M1	**High**

DISCUSSION

Reagents such as collectors, frothers, surface modifiers, activators, pH regulators, and depressants are critical in mineral processing. Reagents are used to maximize the recovery of all the metals, which control physical and chemical conditions of solid, air, and liquid phases, respectively (Dunne, 2005; Marsden and House, 2009; Salarirad and Behnamfard, 2010). In addition to being efficient in terms of production, at the same time, reagents also have potential hazards that can adversely affect workers' health (Scott *et al.*, 2009; Bararunyeretse *et al.*, 2017).

This study evaluated seven chemicals used in the flotation plant: magnafloc, xanthate, promoter, frother, rheomax, solutrix , and lime. Three out of seven chemicals have the potential to expose workers through inhalation, namely xanthate (RR=12), frother (RR=9), and lime (RR=9) have inhalation exposure potential to the workers. Meanwhile, five out of seven chemicals, namely xanthate (RR=M2), promoter (RR=H2), frother (RR=H2), solutrix (RR=M2), and lime (RR=H2) have dermal exposure potential to the workers. Based on the results, the health risks potential related to dermal exposure is higher than inhalation exposure.

The results show that all chemicals related to inhalation hazards are categorized under medium risk, where xanthate has the highest risk rating. The previous study stated that xanthates are the most commonly used sulfide minerals collectors. However, at the same time they are associated with some toxicological, ecological, and health and safety issues (Noirant *et al.*, 2019)..Inhalation exposure to xanthate may cause respiratory irritation, drowsiness, and dizziness, which can be accompanied by narcosis, decreased alertness, loss of reflexes, lack of coordination, and vertigo (Queensland Government, 2018; Chemwatch, 2019). Xanthates are also known to hydrolyze in aqueous solutions and flotation slurries to produce carbon disulfide (CS2), accumulating in flotation plants and posing a significant risk. Long-term exposure to high levels of carbon disulfide is responsible for nervous system effects, including fatigue, insomnia, headache and irritability, and increased susceptibility to heart disease, including heart attack, hypertension, angina, eye damage, reproductive effects, and hearing loss (International Labour Organization (ILO), 2018; Queensland Government, 2018).

According to the results of dermal exposure, three out of five chemicals fell into the high-risk category, namely promoter, frother, and lime. Two out of the five fell into the moderate risk category, namely xanthate, and solutrix. Adverse health effects from chemical exposures involve irritation, corrosion, and sensitization.

The considered factors in assessing the degree of dermal exposure are the extent and duration of dermal contact. Based on the observations and interviews, we determined that the dermal contact risk falls under the small-area skin contact category, which indicates that direct contact is limited only to the palm (<2% or 0.04 m^2). Due to the use of large-scale quantities of reagents, mixing reagents is mainly done with automated equipment where there is little human interaction. It was also assessed to be under the long-term duration category, given that reagents used in a flotation process are used daily.

Taking into account the results, both inhalation and dermal exposure to the workers can result in adverse health outcomes. Although the health effects of chemical exposures are well established, long-term health outcomes will likely occur in years to come. However, the use of hazardous chemicals in the mining industry will continue to increase in the coming years, leading to a higher burden of disease. Appropriate controls is urgently needed to protect the workers exposed by minimizing the exposure.

There are some actions identified to minimize chemical exposure, such as proper storage of chemicals, all the PPEs required for mixing chemicals are adequately maintained to be in good condition and properly used by the workers, all safety equipment, i.e. emergency showers, eyewash, fire extinguishers, hose reels, etc shall be periodically inspected to ensure they are in good fit-for-purpose condition.

Concerning the xanthates exposure to the workers, it is recommended that the xanthates containers must be stored with sufficient ventilation to prevent humidity build-up in the storage area. In addition, CS_2 levels in areas with known high levels of exposure, such as mixing and storage areas, should be monitored and adequately separated from incompatible materials and eliminate human involvement in the mixing process. Figure 1 is SiBX de-bagging process and mixing tank hopper. The workers manually cut off the bags containing the xanthates pellet, which diluted into solution later. During the de-bagging process, a knife used to open a bag is not a standard practice. Instead, the use of a bag spike shown in Figure 2 would be useful if the handle could be modified longer to open the valve and could be accessed outside the suspended load zone. Minimizing human interaction with the hazard effectively minimizes exposure to the worker's body.

Source: Personal Documentation
Figure 1. SiBX de-bagging process and mixing tank hopper

Source: (Materials Handling Pty Ltd, 2019; Rata Industries Group, 2019)
Figure 2. Forklift jib and bag spike

CONCLUSION

Chemicals used in metallurgy production in the gold and copper mining company is used on a massive scale leading to a significant risk of hazardous chemical exposure, either in inhalation or dermal contact. The employees' work environment and activities under assessment are accepted as they are controlled by monitoring the work environment. However, the company shall implement the elimination, engineering, administrative, and personal protective equipment (PPE) control to minimize the workers' inhalation and dermal exposure risk.

SUGGESTIONS

Implementing an engineering control by modifying the tank hopper incorporated with a custom design cutter is recommended. Administrative controls should be considered, such as training, labeling reagent containers, cleaning equipment properly after mixing and use, rotating stock, and keeping minimal stock in storage. PPE is also essential to minimize exposure by using an appropriate respirator, goggles, and protective clothing, including appropriately rated coveralls, gloves, boots, and a safety helmet.

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CONFLICT OF INTEREST

Author have no conflict of interest.

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AUTHOR CONTRIBUTION

Author Yenni Miranda Savira as Data collection, data analysis, manuscript writing, literature review, and references. Author Arif Susanto as a Study design, data collection and supervision, data analysis, and manuscript revision. Author Aprilia Listiarini as Data collection, manuscript writing, literature review, and references. Author Wiliam E. Yochu as study design, data analysis, literature review, and references. Author Edi K. Putro as a supervision, data analysis, manuscript revision. Author Danny R. Santoso as data analysis, literature review, and references. Author John C. Willmot as a supervision, data analysis, and manuscript revision. Author Anita Johan as data analysis, and manuscript revision.

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