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ORIGINAL ARTICLE

Chemical Dermal Exposure Risk Assessment in the Water Treatment Plant of Fertilizer Industry

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ABSTRACT

Introduction: In water treatment plants (WTP), chemicals play a crucial role. However, some of these chemicals are hazardous. This study aims to conduct a dermal risk assessment in the WTP of an ammonia and urea production facility. **Methods:** The study was performed in August 2023 and assessed dermal exposure risk for four hazardous chemicals: NaOCl (30%), HCl (60%), H2SO4 (98%), and NaOH (48%), utilizing the Tier 2 RISKOFDERM model. Intrinsic toxicity was evaluated using risk phrases and toxicity information. Potential dermal exposure rates (PERBODY and PERHANDS) were determined based on task group and exposure modifier, while actual dermal exposure rates (AERBODY and AERHANDS) were determined based on clothing type and activity time. Health risk was assessed using actual exposure scores and intrinsic toxicity levels, which were categorized into 10 different levels ranging from 1 to 10. **Results:** The risk phrases indicated that four chemicals possessed a high level of intrinsic toxicity in terms of local effect but no systemic effect. PERBODY and PERHANDS were high (NaOCl, HCl) and low (H2SO4, NaOH). The actual exposure scores were determined to be 1 (high) for NaOCl and HCI, 0.01 (low) for H2SO4, and 0.03 (medium) for NaOH. Health risk values were 8 for NaOCl and HCI, 5 for H2SO4, and 6 for NaOH. **Conclusion:** Health risks in NaOCl and HCl were assigned action priority (AP) 1, followed by NaOH at AP-2, and H2SO4 at AP-3. The study recommends the implementation of control measures encompassing engineering solutions, administration, and personal protective equipment.

Keywords: chemical, dermal, risk assessment, water treatment plant

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INTRODUCTION

A water treatment plant (WTP) is a utility facility that is designed to clean and treat water that will be used in the process. In the water treatment plant, chemicals play a crucial role as biocides and disinfectants, coagulants and flocculants, corrosion and scale inhibitors, and pH control. The market for water treatment chemicals has grown from the early 1990s and was projected to continue expanding through 2020 (Gitis and Hankins, 2018). Many workers across multiple sectors are exposed to chemicals, and the number is expected to increase as the use of chemicals increases. In the United States, skin exposure to chemicals at work is a serious issue. Skin conditions are more prevalent than respiratory disorders, both in terms of incidence and rate. The Bureau of Labor Statistics (BLS) recorded 25,000 recordable skin diseases in 2018, or 2.2 injuries per 10,000 employees, while respiratory ailments accounted for 19,600 illnesses, or 1.7 illnesses per 10,000 employees.

The vast majority of chemicals are easily absorbed through the skin, potentially increasing the amount of the chemicals inhaled from the air and leading to additional health implications. Numerous studies show that workers may absorb toxins through their skin without realizing it (Occupational Safety and Health Administration, 2018). According to data from the BPJS Ketenagakerjaan program on occupational diseases and accidents between 2019 and 2021, the chemical and basic industry sectors are among the top five business sectors with the highest frequency of work accident cases (12.1%).

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There were 145, 109, and 101 work-related chemical exposure accidents. Indonesia's occupational diseases data for 2019–2022 showed 48, 81, and 6 cases, respectively (Kementerian Ketenagakerjaan RI, 2022).

A health risk assessment can be carried out using several methods. Dermal exposure analysis uses Tier 1 tools such as ECETOCC TRA, MEASE, and EMKG-EXPO-TOOL for basic screening. These tools quickly distinguish between dangerous and non-dangerous situations, providing a conservative estimate of exposure based on a few exposure determinants. They are designed to provide a higher estimate than workplace measurements. Stoffenmanager, Advanced REACH Tool (ART), and Risk Assessment of Occupational Dermal Exposure to Chemicals (RISKOFDERM) are examples of higher-tier tools that could provide more advanced and accurate exposure estimations (Schlueter and Tischer, 2020). The use of risk assessment methods depends on the research objectives.

The Dutch Institute TNO led the European Research Project RISKOFDERM, which involved 15 institutes across 10 member states comprising Germany, Spain, France, Italy, the Netherlands, Austria, Portugal, Finland, Sweden, and the United Kingdom. A toolset for evaluating and controlling health risks from skin exposure is created by RISKOFDERM. This toolkit has an algorithm that evaluates the risk by fusing a hazard score for the substance based on general toxicity and the exposure estimate from the RISKOFDERM model; however, it ignores dermal permeability (Oppl *et al*., 2003). RISKOFDERM is one of the five models recommended for human risk assessment since it can be applied at virtually any step of manufacturing (Franken *et al*., 2020). PT X is a subsidiary of a state-owned enterprise (BUMN) that operates in the fertilizer and chemical industry. To meet the need for nitrogen-based fertilizer, in 2018 PT X built a new production unit, namely the Ammonia, Urea, ZA Factory. Based on PT X internal report, the largest use of auxiliary chemicals is in the water treatment plant. Of the six chemicals used, five chemicals have a route of entry through the skin. Notably, sodium hypochlorite (NaOCl), HCI, sulfuric acid (H2SO4), and sodium hydroxide (NaOH) are classified as H Code H314 (skin corrosion) category I B and H318 (eye damage category 1).

The risk of accidents at the WTP is related to chemicals that have a medium to high level of risk (Falakh and Setiani, 2018). Between 2020 and 2023, there were 13 chemical-related accidents, with outcomes ranging from first aid injuries (FAI) to medical treatment injuries (MTI) in PT X. The procedure at WTP involves the use of numerous chemicals, as well as human contact. However, a health risk assessment of chemical exposure to determine the level of health risk (Risk Rating/RR), which is crucial for company management, has never been undertaken.

METHODS

This research was conducted in August 2023 using descriptive research with a semiquantitative approach. Data collection methods included secondary data, field observations, and semiquantitative dermal risk assessment. The RISKOFDERM model, with the variables Dermal Exposure Operation (DEO) units, Potential Dermal Exposure Rate, Actual Dermal Exposure Rate, Actual Exposure Score, and Control selected for the dermal risk study of chemicals in this research.

Hazard information was obtained from risk phrases according to the European Dangerous Substances Directive used in the RISKOFDERM toolkit. Risk phrases are ranked into an intrinsic toxicity (IT) score, which then equals the hazard score (Table 1). Dermal exposure is defined as Dermal Exposure Operation (DEO) units (Figure 1) because it is believed that, in its appropriate dimensions, it can be extrapolated from one component to another when based on a particular activity. DEO aims to group dermal exposure situations that have a similar relationship between exposure and exposure level. Modifying factors (substance-related, workplace-related, and control-related) also have an impact on the DEO default value; however, their effects differ depending on the exposure route (direct contact, surface contact, or exposure by deposition) (Van Hemmen, 2005).

Table 1. Score for Intrinsic Toxicity for Local Health Effects

R-Phrase	Intrinsic Toxicity (IT) Score
None of those below	Low
R 66, R 38	Moderate
R 34, pH<2 or pH≥11.5	High
R 35, R 43	Very High
R 45	Extreme

Source: Oppl *et al*. (2003)

Potential exposure occurs when a chemical reaches the exterior of the body. RISKOFDERM has determined the Default Potential Exposure Rate (DPEBODY and DPEHANDS) in units of mg cm-2 h-1 based on the DEO unit. Potential Dermal Exposure Rate (PER) is the product of the default potential exposure rate and the overall modifier (Equation 1). If the exposed body part is unprotected, then the actual exposure (AER) is assumed to be equal to the potential exposure (PER). However, if protected by clothing or protective equipment (such as gloves, aprons, and helmets), then the amount of protection depends on the percentage of coverage, the thickness of the clothing, and the physical state of the chemicals encountered (dust or liquid) (Oppl *et al*., 2003).

Actual Dermal Exposure Rate (AER) is the multiplication of PER with a modifying factor, namely 0.5 (light clothing) or 0.1 (thick clothing)

1 Handling of objects
- Filling
- Collecting
- Maintenance and servicing
- Loading
- Mixing/diluting

2 Manual dispersion of substance
- Wiping

3 Dispersion of substance with hand-held tool
- Pouring
- Spreading with comb
- Rolling
- Brushing

4 Spray dispersion of substance
- Spraying

5 Immersion
- Immersing of objects (electroplating)

6 Mechanical treatment (of solid objects)
- Machining
- Grinding
- Sawing

Figure 1. Dermal Exposure Operation (DEO) Units Based on RISKOFDERM Models
Source: Van Hemmen (2005)

$$PER_{BODY} = \text{default potential exposure rate (body)} \times \text{overall modifiers} \quad (1a)$$

$$PER_{HANDS} = \text{default potential exposure rate (hands)} \times \text{overall modifiers} \quad (1b)$$

Equation 1. Potential Dermal Exposure Rate
Source: Oppl *et al*. (2003)

(Equation 2). However, RISKOFDERM does not consider the use of protective clothing or gloves because they may not provide adequate protection. In addition, it depends on how they are put on and taken off. Thus, AERHANDS in Equation 2 is the same as PERHANDS.

The actual peak exposure level score (AERPEAKscore) was assigned to the exposure level for the hand, which was determined to be the best estimate of the peak exposure level (AERPEAK). The actual exposure dose (AED) is the product of the AERHANDS score and Activity Time (AT) (Equation 4). The exposed body area (EBA) score is obtained based on information in the field regarding which parts of the body are exposed. Actual Exposure (AE) score is the product of AED score and EBA score (Equation 5).

The health risk score is derived by combining the Hazard score matrix from Intrinsic Toxicity (Table 1) with the Actual Exposure (AE) score (Table 2), resulting in a scale of 10 levels of health risk. The scale ranges from 1, indicating the lowest health risk, to 10, representing the highest risk value (Table 3).

Dermal Exposure Operation (DEO) Units

Sodium hypochlorite and HCl handling activities at the WTP of PT X consisted of manually

$$AER_{BODY} = \text{potential exposure rate (body)} \times \text{clothing reduction factor} \quad (2a)$$

$$AER_{HANDS} = \text{potential exposure rate (hands)} \times \text{clothing reduction factor} \quad (2b)$$

Equation 2. Actual Dermal Exposure Rate
Source: Oppl *et al*. (2003)

$$AER_{PEAK}\text{ score} = \text{value of actual exposure rate of the hands (see eq. 2b)} \quad (3)$$

Equation 3. Actual Dermal Exposure Rate Peak
Source: Oppl *et al*. (2003)

$$AED_{PEAK}\text{ score} = AER_{PEAK}\text{ score} \times \text{AT score} \quad (4)$$

Equation 4. Actual Exposure Dose
Source: Oppl *et al*. (2003)

$$AE_{PEAK}\text{ score} = AED_{PEAK}\text{ score} \times \text{EBA score} \quad (5)$$

Equation 5. Actual Exposure Score
Source: Oppl *et al*. (2003)

pouring the chemical from pails into the process tank, while sulfuric acid (H_2SO_4) was used in a closed system, ensuring that it was only used when maintenance activities were required. Sodium hydroxide (NaOH) was transported using an isotank, and there was a potential for contact when unloading NaOH from the isotank to the process line. As seen in Figure 1, the four activities are based on DEO Unit 1, namely the handling of contaminated liquid objects with the type of contact surface contact. Contribution Factors (CFB) for DEO Unit 1, as determined by the RISKOFDERM toolkit, are 100% (body and hands). The Default Potential Exposure Rate (DPE) values are 0.2 (high) for the body and 0.656 (high) for the hands.

Potential Dermal Exposure Rate

Potential Dermal Exposure Rate (PER) is a qualitative score obtained based on task group and exposure modifier (substance, workplace, or control). Based on observations in the field with reference to the RISKOFDERM toolkit, the exposure modifiers for NaOCl and HCl are 'like water', unrestricted workspace, fully manual, and natural ventilation. Meanwhile, the exposure modifiers for H2SO4 are touch dry/small areas of contamination, unrestricted workspace, fully automated, and natural ventilation. For NaOH, the exposure modifiers are touch dry/small areas of contamination, unrestricted workspace, partially automated partially manual, and natural ventilation. PER is calculated on the body (PERBODY) and on the hands (PERHANDS).

Table 2. Peak Actual Exposure (AE) Score Local Health Effects

AEDPEAK score x EBA score	Actual Exposure AEPEAK scores
0.002 or less	Negligible
>0.002-0.02	Low
>0.02-0.2	Moderate
>0.2-2	High
>2-20	Very high
>20	Extreme

Source: Oppl *et al*. (2003)

Table 3. Health Risk Score for Local Health Effects

Actual Exposure Score (Local)	Hazard Score (Local)				
	Low (No Risk)	Moderate	High	Very High	Extreme
Negligible	1	1	2	5	8
Low	1	2	5	5	10
Moderate	2	3	6	6	10
High	2	4	6	8	10
Very High	3	7	7	9	10
Extreme	7	9	9	9	10

Source: Oppl *et al*. (2003)

Actual Dermal Exposure Rate

Actual Dermal Exposure Rate (AER) BODY is a qualitative score obtained from the PERBODY value by considering the type of workwear used. Meanwhile, AERHANDS is the same as PERHANDS because the use of hand protection is not taken into account in this assessment.

Actual Exposure Score

Actual Exposure (AE) score is obtained by multiplying the Actual Exposure Dose by the Exposure Body score according to the RISKOFDERM toolkit. Actual Exposure Dose is obtained based on the AER Hands score multiplied by the Activity Time score.

Control

The risk of chemicals to health is displayed by the health score value, which is a combination between the AE score and the Hazard score. In the event that the resulting risk is sufficiently low, no further requirements arise from the risk assessment. However, if not, additional control measures are needed and a new risk assessment is recommended to determine their effectiveness. The RISKOFDERM project group established several risk control efficiency classes following European law (Chemical Agents at Work Directive 98/24/EEC), namely the

Table 4. Action Priority Determination Based on CHRA DOSH Malaysia

Level of Risk	Adequacy of Control	Action Priority (AP)
High	Inadequate	1
Health Risk Could Not Be Determined	-	
Moderate/ Low	Inadequate	2
High/Moderate/ Low	Adequate	3

Source: Department of Occupational Safety and Health Ministry of Human Resources Malaysia (2018)

STOP principle: Substitution, Technical Protection, Organizational Protection, and Personal Protection (Van Hemmen, 2005). The Chemical Health Risk Assessment (CHRA) of the Department of Occupational Safety and Health (DOSH) Malaysia is used to determine action priorities based on the level of risk and adequacy of control (Table 4).

RESULTS

Chemical Health Risk Assessment using the RISKOFDERM model was carried out at the WTP unit. From the results of this analysis, the four chemicals used, sodium hypochlorite, HCI, sulfuric acid (H2SO4), and sodium hydroxide (NaOH), had a health hazard with the risk phrases R34 (causes burns) with an intrinsic toxicity score in the high category and were not identified as having systemic effects.

Table 5 shows the complete computation and analysis results of RISKOFDERM. The potential dermal exposure rate (PERBODY and PERHANDS) was in the high category for NaOCl and HCl and in the low category for H2SO4 and NaOH. Meanwhile, the actual dermal exposure rate of AERBODY was 0.1 times that of PERBODY, while AERHANDS was the same as PERBODY. The Actual Exposure score was high for two chemicals (sodium hypochlorite and HCI), medium for NaOH, and low for H_2SO_4. The results of the health risk score analysis was 8 for two chemicals, 6 for one chemical, and 5 for one chemical, on a scale of 10. The results are presented in Table 5.

DISCUSSION

NaOCl and HCl

Sodium hypochlorite is generally used in solution form, while its solid form is not used for commercial purposes. The solution is a clear liquid, yellowish green in color with a chlorine odor. If it reacts with acid, it can release chlorine gas (Pubchem, 2023c). The benefits of hypochlorite treatment include a simple, quick, and efficient procedure, a high capacity, minimal sludge production, the ability to recycle water, and disinfection by bacteria and viruses (Crini and Lichtfouse, 2019).

Sodium hypochlorite, a known irritant, has also been reported to cause type IV allergic contact dermatitis, depending on exposure time and concentration. Some other reported cases include immediate urticarial rash (with 0.1% sodium hypochlorite solution), edema and progression to erythema lesions, necrosis of subcutaneous tissue layers and third-degree burns (>4% sodium hypochlorite). This case has been reported to arise due to accidents or exposures to sodium hypochlorite both in the work environment and at home (Chung *et al*., 2022). The potential toxicity of hypochlorite is related to its ability to oxidize and the pH of its solution, causing damage to the skin and mucous membranes due to its corrosive properties. Prolonged or extensive skin exposure can cause skin irritation and damage, as well as dermal hypersensitivity, with the possibility of immediate or delayed skin reactions, especially in high-concentration solutions that can cause serious chemical burns (Slaughter *et al*., 2019).

Hydrochloric acid is a clear, sharp-smelling solution that is often used in chloride, fertilizer, dye, electroplating, textile and rubber industries. It is corrosive to the eyes, skin, and mucous membranes in acute exposure, and chronic exposure can cause dermatitis. The Environmental Protection Agency (EPA) does not classify this substance as carcinogenic.

More concentrated bleach contains 10-15% sodium hypochlorite, which has a pH of approximately 13 and is corrosive. In contrast, household bleach typically contains around 5% sodium hypochlorite, with a pH of about 11 and can cause irritation (ILO, 2021). In the WTP unit of PT X, the concentration of NaOCl used was 30% and HCl was 60%; therefore, they are corrosive to the dermis. Exposure to hydrochloric acid can cause skin burns, ulcerations, and vision problems as side effects. Repeated exposure may cause dermatitis (Pubchem, 2023a).

The calculation of the Potential Dermal Exposure Rate (PERBODY and PERHANDS) indicated high exposure levels to NaOCl and HCl due to the manual chemical addition activities in the PT X's WTP unit. Pouring liquids from buckets into the reaction tank poses a risk of exposure to body parts, such as hands, forearms, and head (2,800 cm2). According to field operators, the duration of this work was around 15 minutes per shift. The company provided personal protective equipment, specifically rubber gloves and face shields; however, based on the observations in the field, compliance with the use of this equipment was still low. This was evidenced by an incident in September 2023

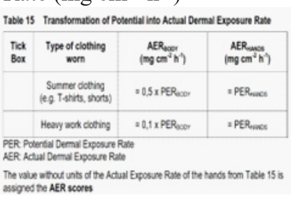
Table 5. Results of Risk Analysis of Dermal Exposure of Four Chemicals (NaOCl, HCl, H_2SO_4, NaOH)at the Water Treatment Plant Unit of PT X in 2023

Variable	NaOCl (30%)	HCl (60%)	H2SO4 (98%)	NaOH (48%)
Hazard Score/ Intrinsic Toxicity (IT) Score	H314, H318 Risk Phrases: R34 (Causes Burns) Local Effect ITL Score: High	H314, H318 Risk Phrases: R34 (Causes Burns) Local Effect ITL Score: High	H314, H318 Risk Phrases: R34 (Causes Burns) Local Effect ITL Score: High	H314 Risk Phrases: R34 (Causes Burns) Local Effect ITL Score: High
Dermal Exposure Operation (DEO)	Pouring the chemical from the pail into the process tank DEO = 1 (Handling of Contaminated Objects (Liquid) Type of contact = Surface Contact (SC)	Pouring the chemical from the pail into the process tank DEO = 1 (Handling of Contaminated Objects (Liquid) Type of contact = Surface Contact (SC)	Maintenance of line H2SO4 DEO = 1 (Handling of Contaminated Objects (Liquid) Type of contact = Surface Contact (SC)	Connect line NaoH from isotank into process line DEO = 1 (Handling of Contaminated Objects (Liquid) Type of contact = Surface Contact (SC)
Contribution Factors (CFB in %)	Body Exposure = CFB_{SC} 100% $Hand_{s\ Exposure\ =}$ CFH_{SC} 100%	Body $_{Exposure\ =\ CFBSC}$ 100% Hands Exposure = CFH_{SC} 100%	Body $_{Exposure\ =\ CFBSC}$ 100% Hands Exposure = CFH_{SC} 100%	Body $_{Exposure\ =\ CFBSC}$ 100% Hands Exposure = CFH_{SC} 100%
Default Potential Exposure Rate (DPE)	DPE_{BODY} = 0.2 (High) DPE_{HANDS} = 0.656 (High)	DPE_{BODY} = 0.2 (High) DPE_{HANDS} = 0.656 (High)	DPE_{BODY} = 0.2 (High) DPE_{HANDS} = 0.656 (High)	DPE_{BODY} = 0.2 (High) DPE_{HANDS} = 0.656 (High)
Exposure Modifier				
Correction Factors for Substance-related Modifiers Integrated Modifying Factor (MFI) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} $MFI_{HANDS} = MF_{SC}$ x CFH_{SC}	Like water (MF_{SC} = 1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 1 x 100% = 1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 1 x 100% = 1	Like water (MF_{SC} = 1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 1 x 100% = 1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 1 x 100% = 1	Touch dry/ small areas of contamination (<20%) (MF_{SC} = 0.1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 0.1 x 100% = 0.1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 0.1 x 100% = 0.1	Touch dry/ small areas of contamination (<20%) (MF_{SC} = 0.1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 0.1 x 100% = 0.1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 0.1 x 100% = 0.1
Correction Factors for Workplace-related Modifiers Integrated Modifying Factor (MFI) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} $MFI_{HANDS} = MF_{SC}$ x CFH_{SC}	Unrestricted workspace (MF_{SC} = 1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 1 x 100% = 1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 1 x 100% = 1	Unrestricted workspace (MF_{SC} = 1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 1 x 100% = 1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 1 x 100% = 1	Unrestricted workspace (MF_{SC} = 1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 1 x 100% = 1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 1 x 100% = 1	Unrestricted workspace (MF_{SC} = 1) MF_{SC} = 0.1) $MFI_{BODY} = MF_{SC}$ x CFB_{SC} = 0.1 x 100% = 0.1 $MFI_{HANDS} = MF_{SC}$ x CFH_{SC} = 0.1 x 100% = 0.1

Advanced Table 5. Results of Risk Analysis of Dermal Exposure of Four Chemicals (NaOCl, HCl, H_2SO_4, NaOH)at the Water Treatment Plant Unit of PT X in 2023

Variable	NaOCl (30%)	HCl (60%)	H2SO4 (98%)	NaOH (48%)
Correction Factors for Control-related Modifiers MFI_{BODY} = MF_{SC} x CFB_{SC} MFI_{HANDS}= MF_{SC} x CFH_{SC}	No automation, fully manual (MF_{SC} = 1) MF_{IBODY} = MF_{SC} x CFB_{SC} = 1 x 100% = 1 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 1 x 100% Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 1 x 100% = 1 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 1 x 100%	No automation, fully manual (MF_{SC} = 1) Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 1 x 100% = 1 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 1 x 100% Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 1 x 100% = 1 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 1 x 100%	Fully automated (MF_{SC} = 0.1) Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 0.1 x 100% = 0.1 $MFIH_{ANDS}$= MF_{SC} x CFHSC = 0.1 x 100% = 0.1 Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 1 x 100% = 1 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 1 x 100%	Partially Automated partially manual (MF_{SC} = 0.3) Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 0.3 x 100% = 0.3 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 0.3 x 100% = 0.3 Natural Ventilation (MF_{SC} = 1) MFI_{BODY} = MF_{SC} x CFB_{SC} = 1 x 100% = 1 MFI_{HANDS}= MF_{SC} x CFH_{SC} = 1 x 100%
Modifying Factor per Group (MFG) $MFG(a)_{BODY}$ = MFI_{BODY} - MODIFIER 1 x MFI_{BODY} - MODIFIER 2 x MFI_{BODY} - MODIFIER 3 x … $MFG(a)_{HANDS}$ = MFI_{HANDS} - MODIFIER 1 x MFI_{HANDS} - MODIFIER 2 x MFI_{HANDS} - MODIFIER 3 x … Total Modifying Factor (MFT_{BODY}) = $MFG(a)_{BODY}$ x $MFG(b)_{BODY}$ x $MFG(c)_{BODY}$ (MFT_{HANDS}) = $MFG(a)_{BODY}$ x $MFG(b)_{BODY}$ x $MFG(c)_{BODY}$	Modifying Factor per Group (MFG) $MFG(a)_{BODY}$ = 1 $MFG(a)_{HANDS}$ = 1 $MFG(b)_{BODY}$ = 1 $MFG(b)_{HANDS}$ = 1 $MFG(c)_{BODY}$ = 1 x 1 = 1 $MFG(c)_{HANDS}$ = 1 x 1 = 1 MFT_{BODY} = 1 x 1 x 1 = 1 MFT_{HANDS} = 1 x 1 x 1 = 1	Modifying Factor per Group (MFG) $MFG(a)_{BODY}$ = 1 $MFG(a)_{HANDS}$ = 1 $MFG(b)_{BODY}$ = 1 $MFG(b)_{HANDS}$ = 1 $MFG(c)_{BODY}$ = 1 x 1 = 1 $MFG(c)_{HANDS}$ = 1 x 1 = 1 MFT_{BODY} = 1 x 1 x 1 = 1 MFT_{HANDS} = 1 x 1 x 1 = 1	Modifying Factor per Group (MFG) $MFG(a)_{BODY}$ = 0.1 $MFG(a)_{HANDS}$ = 0.1 $MFG(b)_{BODY}$ = 1 $MFG(b)_{HANDS}$ = 1 $MFG(c)_{BODY}$ = 0.1 x 1 = 0.1 $MFG(c)_{HANDS}$ = 0.1 x 1 = 0.1 MFT_{BODY} = 0.1 x 1 x 0.1 = 0.01 MFT_{HANDS} = 0.1 x 1 x 0.1 = 0.01	Modifying Factor per Group (MFG) $MFG(a)_{BODY}$ = 0.1 $MFG(a)_{HANDS}$ = 0.1 $MFG(b)_{BODY}$ = 1 $MFG(b)_{HANDS}$ = 1 $MFG(c)_{BODY}$ = 0.3 x 1 = 0.3 $MFG(c)_{HANDS}$ = 0.3 x 1 = 0.3 MFT_{BODY} = 0.1 x 1 x 0.3 = 0.03 MFT_{HANDS} = 0.1 x 1 x 0.3 = 0.03

Advanced Table 5. Results of Risk Analysis of Dermal Exposure of Four Chemicals (NaOCl, HCl, H_2SO_4, NaOH)at the Water Treatment Plant Unit of PT X in 2023

Variable	NaOCl (30%)	HCl (60%)	H2SO4 (98%)	NaOH (48%)
Potential Dermal Exposure Rate (mg cm^{-2} h^{-1}) PER_{BODY} = MFT_{BODY} x DPE_{BODY} PER_{HANDS} = MFT_{HANDS} x DPE_{HANDS}	PER_{BODY} = 1 x 0.2 = 0.2 (High) PER_{HANDS} = 1 x 0.656 = 0.656 (High)	PER_{BODY} = 1 x 0.2 = 0.2 (High) PER_{HANDS} = 1 x 0.656 = 0.656 (High)	PER_{BODY} = 0.01 x 0.2 = 0.002 (Low) PER_{HANDS} = 0.01 x 0.656 = 0.00656 (Low)	PER_{BODY} = 0.03 x 0.2 = 0.006 (Low) PER_{HANDS} = 0.03 x 0.656 = 0.01968 (Low)
Actual Dermal Exposure Rate (mg cm^{-2} h^{-1})  Table 15 Transformation of Potential into Actual Dermal Exposure Rate Tick Box / Type of clothing worn / AER_{BODY} (mg cm^{-2} h^{-1}) / AER_{HANDS} (mg cm^{-2} h^{-1}) Summer clothing (e.g. T-shirts, shorts) / = 0,5 x PER_{BODY} / = PER_{HANDS} Heavy work clothing / = 0,1 x PER_{BODY} / = PER_{HANDS} PER: Potential Dermal Exposure Rate AER: Actual Dermal Exposure Rate The value without units of the Actual Exposure Rate of the hands from Table 15 is assigned the **AER scores**	Heavy Work Clothing AER_{BODY} = 0.1 x 0.2 = 0.02 mg cm^{-2} h^{-1} AER_{HANDS} = PERHANDS = 0.656 mg cm^{-2} h^{-1}	Heavy Work Clothing AER_{BODY} = 0.1 x 0.2 = 0.02 mg cm^{-2} h^{-1} AER_{HANDS} = PERHANDS = 0.656 mg cm^{-2} h^{-1}	Heavy Work Clothing AER_{BODY} = 0.1 x 0.002 = 0.0002 mg cm^{-2} h^{-1} AER_{HANDS} = PERHANDS = 0.00656 mg cm^{-2} h^{-1}	Heavy Work Clothing AER_{BODY} = 0.1 x 0.006 = 0.0006 mg cm^{-2} h^{-1} AER_{HANDS} = PERHANDS = 0.01968 mg cm^{-2} h^{-1}
Exposed Body Parts	Lower Arms = 1,400 cm^2 Head = 1,400 cm^2 Total = 2,800 cm^2 EBA Score = 1	Lower Arms = 1,400 cm^2 Head = 1,400 cm^2 Total = 2,800 cm^2 EBA Score = 1	Small Area <10 cm^2 EBA Score = 0.1	One Hand or Less = 900 cm^2 EBA Score = 0.3
Activity Time (AT)	Duration = 0.1 - < 0.5 h/day AT Score = 3	Duration = 0.1 - < 0.5 h/day AT Score = 3	Duration = <0.1 h/day AT Score = 1	Duration = 0.1 - < 0.5 h/day AT Score = 3
Actual Exposure Dose (AED) AED = AER (HANDS) x AT Score	AED = 0.656 x 3 = 1.968 → AED Score = 1	AED = 0.656 x 3 = 1.968 → AED Score = 1	AED = 0.00656 x 1 = 0.00656 → AED Score = 0.1	AED = 0.01968 x 3 = 0.05904 →AED Score = 0.3
Actual Exposure (AE) Score AE = AED Score x EBA Score	AE Score = 1 x 1 = 1 (High)	AE Score = 1 x 1 = 1 (High)	AE Score = 0.1 x 0.1 = 0.01 (Low)	AE Score = 0.3 x 0.3 = 0.09 (Moderate)
Health Risk Score Matrix AE Score dan Hazard Score	Health Risk Score = 8 (Only exceptionally tolerable, substitute, if any possible)	Health Risk Score = 8 (Only exceptionally tolerable, substitute, if any possible)	Health Risk Score = 5 (Hazard reduction desirable)	Health Risk Score = 6 (Action necessary: mixtures of measures, priority for detailed analyses)

where a worker suffered from skin irritation on his hands after being splashed with this liquid. Moreover, field operators never received proper training or awareness regarding chemical handling, leading to insufficient risk control measures for NaOCl and HCl.

Based on the analysis results, the Health Risk score of NaOCl and HCl was 8 (high), indicating that they were only exceptionally tolerable. Therefore, if possible, it is recommended to substitute and implement additional control measures. Referring to the CHRA DOSH Malaysia action priority determination (Table 4), risks related to exposure to NaOCl and HCl at PT X had action priority 1.

RISKOFDERM formulates risk control through a STOP principle of control: Substitution, Technical Protection, Organizational Protection, and Personal Protection. The hazard control concepts are identical to those outlined in NIOSH's hierarchy of control, which include elimination, substitution, engineering control, administration, and personal protective equipment (NIOSH, 2023). There are several recommendations that can be implemented at the WTP unit of PT X. Firstly, changing from manual chemical pouring to using a pump as an engineering control measure is highly recommended. Additionally, providing training related to chemical handling and its health risks would be beneficial as an administrative control measure. Lastly, it is essential to ensure the suitability and proper use of PPE such as rubber gloves and face shields, while also emphasizing the importance of personal hygiene after contact with chemicals. This is in line with other studies on chemical industry that found a correlation between knowledge, attitudes, and comfort toward PPE compliance (Aslamiah and Kurniawan, 2019; Noviarmi and Prananya, 2023; Saputra and Widowati, 2023) .

H2SO4

Sulfuric acid is extremely harmful to the skin, eyes, and mucous membranes. There have been reports of eye injury caused by contact with sulfuric acid from car batteries. The most prevalent injuries are chemical burns to the conjunctiva and cornea, as well as iritis. Dermal burns caused by exposure to sulfuric acid can be fatal (Pubchem, 2024). Exposure to the eyes or skin results in severe burns, the extent of which varies with the potency of the acid. Swallowing may lead to intense irritation of the mouth and stomach. Sulfuric acid accounted for the primary cause (42%) of chemical burns in the Tarapur industrial complex, India, from 2014 to 2015. Half of these sulfuric acid burns involved an acid concentration of 98% (Kulkarni and Jeffery, 2018).

Sulfuric acid (H_2SO_4) used in the utility unit process of PT X originated from its own manufacturing process which was distributed through a closed system using piping, with contact only occurring during maintenance process. The Actual Exposure (AE) score was 0.01 (low) due to the automated addition of H_2SO_4, which was rarely carried out. The assessment results for the Health Risk score revealed a moderate level of 5 out of 10.

The company provided safety showers, acid hazard signs, and adequate personal protective equipment, such as acid-resistant clothing and gloves. However, field operators lacked awareness or training related to chemical handling. Until 2023, no accidents had occurred due to H_2SO_4 splashing at PT X, indicating sufficient control over this risk. Referring to the action priority determination of CHRA DOSH Malaysia (Table 4), the risks related to H_2SO_4 exposure at PT X was categorized as action priority 3. Recommendations include offering training on chemical handling and health risks, as well as ensuring compliance with the use of PPE when conducting maintenance activities.

NaOH

Sodium hydroxide is extremely caustic to a variety of materials and can cause severe chemical burns to the eyes and skin even at low aqueous concentrations (Riddick, 2020). When applied as a solid or as a 50% solution, sodium hydroxide (NaOH) is extremely corrosive and can burn the eyes, skin, and mucous membranes severely. Application of a 5% solution to the skin resulted in significant necrosis after four hours in rabbit trials. Rapidly irrigating the eyes after using a 1% solution poses no harm. Solutions higher than 30% severely corrode skin (Pubchem, 2023b). Based on CLP Regulation No. 1272/2008 Annex VI for acute exposure with short-term local effects, the concentration limit for NaOH corrosivity is considered to be 2% (ECHA, 2023). Sodium hydroxide (22%) was the second most common chemical involved in chemical burns in the Tarapur industrial complex in India from 2014 to 2015 (Kulkarni and Jeffery, 2018).

Sodium hydroxide (NaOH) used in the WTP of PT X had a concentration of 48%. It was transported by the supplier using an isotank, and unloading was carried out on the connector which was already in line with the process. Possible contact with chemicals may occur during product unloading from the isotank and connection process to the NaOH line.

The NaOH connection process from the isotank to the system was carried out by the driver supplier on a weekly basis. The personal protective equipment provided was rubber gloves and face shields, but compliance with their use needed to be ensured. Training on chemical handling and its health risks had never been conducted; therefore, a training session needs to be scheduled. This suggests that control over this risk was not sufficient. According to a study on chemical handlers, a significant portion of chemical managers and handlers are unaware of personal protective equipment (PPE) regulations, emphasizing the importance of increased education and the development of educational content to ensure compliance and safety when handling hazardous chemicals (Han, 2021).

The Health Risk score assessment yielded a moderate result of 6. Based on the action priority determination of CHRA DOSH Malaysia (Table 4), the risks related to NaOH exposure at PT X were classified as action priority 2, requiring for the need for measures such as providing training on chemical handling and its health risks, as well as ensuring compliance with the use of PPE for isotank drivers during unloading activities. According to Manzoor (2020), emergency management competencies of hazardous materials (HAZMAT) truck drivers include prevention, preparedness, mitigation, response, and recovery.

Prevention involves safe driving tactics and knowledge of HAZMAT properties. Mitigation involves first aid, triage, and spill control techniques. Preparedness involves understanding emergency response plans, PPE, and emergency services. Response involves communication, reporting mechanisms, and cordoning off areas to protect people and assets. HAZMAT truck drivers educated as first responders can greatly contribute to emergency mitigation, particularly in low- and middle-income countries, through initial training, on-the-job training, refresher courses, and frequent exercises and drills.

CONCLUSION

Health risk values were 8 for NaOCl and HCI, 5 for H_2SO_4, and 6 for NaOH on a scale of 10. Action priority (AP) 1 was assigned to health risks in NaOCl and HCl handling activities, AP-2 was designated for NaOH, and AP-3 for H2SO4. Recommendations for control can be carried out in accordance with the hierarchy of control. Control that can be carried out through engineering control includes the installation of a pump to facilitate the transfer of chemicals from containers to process tanks. This method prevents workers from coming into direct contact with the chemicals when pouring them. It is important for the company to internally reassess the appropriate pump design.

The next control is administrative control, which includes providing training on chemical handling and its health risks, both for internal workers and third-party chemical providers. The training covers emergency management competencies for hazardous materials (HAZMAT), including prevention, preparedness, mitigation, response, and recovery. Another administrative control is ensuring standard operational procedures are carried out properly. In addition, safety data sheets (SDS), signs, safety showers, and eye wash must also be available at the location.

The final control hierarchy is the use of PPE. Companies should ensure the suitability and use of PPE, such as coveralls, face shields, rubber gloves, and safety shoes. Workers, both organic and third-party employees, must ensure the proper use of PPE during contact with chemicals, as well as personal hygiene after contact with chemicals.

CONFLICT OF INTEREST

The authors declare that there are no substantial competing financial, professional, or personal interests that could have influenced the performance or presentation of this study.

AUTHOR CONTRIBUTOR

RR recognized the problem, developed the assessment, collected data, assessed it, and concluded the assessment results. MT provided guidance on data assessment, reviewed the manuscript, and approved the manuscript.

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