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ORIGINAL ARTICLE

Occupational Chemical Exposure and Risk Assessment among Workers in Power Plant Process, Rayong Province, Thailand

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ABSTRACT

Introduction: The combined cycle power plant involves the use of highly hazardous chemicals, primarily utilized in water quality improvement processes and cooling systems. Employees are susceptible to potential health risks associated with exposure through inhalation, skin, and eye contact. This study aims to assess the risk of chemical exposure among employees in the power plant process. **Methods:** The analysis uses secondary data collected from chemical measurements in the workplace environment during the power plant's three-years of operation. **Results:** The analysis identified hydrogen peroxide, sodium hydroxide, sulfuric acid, and hydrochloric acid as commonly utilized in power plant operations, with exposure occurring primarily through inhalation. While industrial hygiene assessments over the past three years reported atmospheric concentrations below standard limits, health risk assessments highlighted these chemicals as presenting unacceptable but manageable risks to employee health. Furthermore, the presence of mutagenic and highly carcinogenic compounds was observed. Especially, exposure surveillance has not yet been incorporated into the production process for risk evaluation. **Conclusion:** Therefore, the results of the risk assessment indicate that exposure should be monitored by conducting industrial hygiene measurements for highly hazardous chemicals and conducting employee health risk assessments, as required by law, for all types of hazardous chemicals.

Keywords: chemical exposure, occupational health, risk assessment

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INTRODUCTION

Industrial development's growth has driven a continuous rise in energy consumption. In a combined-cycle power plant process, hazardous chemicals are used in water quality improvement processes and cooling systems (Motahari *et al.*, 2023). The major routes of chemical access to the body are the lungs (inhalation), the skin (topical absorption), and the gastrointestinal tract (ingestion) (International Labour Organization, 2021), potentially affecting the workers' health. Besides polluting the environment, these dangerous chemicals can harm worker health in both the short and long term, potentially causing illness or even death (Ansar *et al.*, 2021; Motahari *et al.*, 2023). Human health risk assessment estimates the likelihood and potential negative health effects of chemical exposures on humans, both short-term and long-term exposure assessment identifies potential routes of human exposure to toxic substances, estimating the magnitude, frequency, and duration of both actual and potential exposures (Ayuningtyas and Nasri, 2021; Chaiklieng *et al.*, 2021).

As technology and industry continue to grow, they are fueling an increase in occupational diseases. Across various industries, chemicals are essential raw materials. However, hazardous chemicals are used in

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production processes in diverse ways, depending on the specific type and required amount (Laor *et al.*, 2019). Critically, each hazardous chemical possesses unique properties and associated dangers (Thatsanat and Chaiklieng, 2019). The benefits of chemicals are diverse. However, the effects of chemicals can also be very severe, especially in industrial plants operating businesses related to chemicals. Due to the nature of this industry, which involves the use of many types of chemicals in large quantities, there is a high risk of accidents (Chaiklieng *et al.*, 2021; Rovira and Domingo, 2019). Safety risk analysis is a crucial foundation for occupational safety and health management. It helps create effective plans by systematically evaluating risks associated with employee work activities (Chaivanich, 2022). Chemical health risk assessment aims to control chemical contamination in the environment to safe levels for humans (Jirapongsuwan *et al.*, 2019; Kuntawee *et al.*, 2020). Chemical exposure in workplaces can lead to severe health risks depending on the type of chemical, duration, and mode of exposure. Common workplace chemicals, including solvents, acids, heavy metals, and gases, can have acute or chronic health effects. Key health hazards include respiratory issues, skin conditions, reproductive harm, carcinogenic effects, and damage to vital organs such as the liver and kidneys. (International Labour Organization, 2021; Fatemi, Dehdashti and Jannati, 2022). However, even small amounts of some chemicals can be toxic if exposure occurs over a long period. Not all chemicals with chronic toxicity can be tolerated daily without harm (Tangyosthakijjakul and Chernbamrung, 2018).

The studied power plant is a combined cycle power plant in Rayong Province, Thailand. The majority of chemicals are used in water treatment systems to prevent pipe corrosion and equipment scaling. Coolant chemicals, such as biocides or antifreeze, are used in cooling systems to regulate temperature and prevent microbial growth. Additionally, other chemicals present in the workplace atmosphere that employees are exposed to during their duties include those used in welding work within the maintenance department. Workplace exposure to chemical hazards can cause various health effects influenced by chemical type, concentration, exposure duration, and individual susceptibility. Symptoms include respiratory issues, skin and eye irritation, and systemic effects such as headaches, dizziness, and nausea. Prolonged or high-level exposure to hazardous substances, including carcinogens and mutagens, may lead to chronic illnesses such as respiratory diseases, neurological disorders, and cancer. In severe cases, exposure can result in acute poisoning or organ damage, highlighting the critical need for robust workplace safety measures and regular health monitoring. The purpose of this study is to assess health risk of chemical exposure among workers in power plant process, by using the secondary data. The secondary data of chemical monitoring working environments and frequent exposure to chemicals from the last three years recording of the power plant process were used. This study adheres to legal regulations set forth in the Occupational Safety, Health, and Environment Act B.E. 2554 (A.D.2011) (Occupational Health and Safety and Environment Act B.E. 2554 (A.D. 2011), 2011) and the Notification of the Ministry of Industry: Thailand Industrial Standards for Chemical Health Risk Assessment for Industrial Workers B.E. 2555 (A.D.2012) (Notification of Ministry of Industry: Thailand Industrial Standard for Chemical Health Risk Assessment for Industrial Worker B.E. 2555. (A.D. 2012), 2012)

METHODS

Study Sample Selection

This study utilizes secondary data obtained from industrial hygiene monitoring results spanning three years within the combined-cycle power plant process. Chemical workplace monitoring encompassed 10 types of chemical exposures to assess the health risks of workers in the power plant process, employing guidelines outlined in the notification of the Ministry of Industry: Thailand Industrial Standard for Chemical Health Risk Assessment for Industrial Workers B.E. 2555 (A.D. 2012). (Notification of the Ministry of Industry Thailand, 2012) The approach used is further elaborated in the following explanation.

Occasional Chemical Exposure

Occasional chemical exposure at five levels such as, no exposure, low, medium, high, and very high, respectively. By considering the magnitude of exposure rating (MR) in relation to the chemical concentration levels obtained from industrial hygiene measurements, compared to the Occupational Exposure Limit - Time Weighted Average (OEL-TWA), one can determine how exposure ratings might be assigned. For instance, exposure ratings could range from less than 10%, less than 50%, less than 75%, 75-100%, to more than 100%. If the results are lower than the OEL-TWA, it indicates an acceptable exposure level. However, if the results exceed the OEL-TWA, it indicates an unacceptable level of exposure, necessitating occupational management measures in the workplace. These measures may include elimination, substitution, engineering controls, enforcement, or the provision of personal protective equipment (PPE).

Table 1. The Frequency of Exposure Rating (FR) Affects Health

Level	Criteria	Explanation
1	Rare	Happens in nearly all circumstances such as once a year
2	Likely	Happens in almost all circumstances such as a few times a year
3	Possible	Happens at any time such as a few times per month
4	Unlikely	Rarely happens such as continuous for between 2 and 4 hours per shift
5	Almost certain	Only happens under certain circumstances such as continuous 8 hours shift

Table 2. The Severity of the Health Effects Caused by Hazardous Chemicals

Level	Criteria	Explanation
1	Insignificant	Don't affect health
2	Minor	First aid, on-site handling
3	Moderate	Medical treatment, on-site treatment with outside assistance
4	Major	Serious cases involving severe injuries cannot always be cured, and individuals affected must adjust to living with the illness or its effects.
5	Catastrophic	Fatality or disorder

However, determining the order of exposure to hazardous chemicals is calculated by comparing the average concentration limit of chemicals in the air throughout the working period, or Occupational Exposure Limit - Time Weighted Average (OEL-TWA), with the concentration of the substance obtained from the results of air monitoring in the environment where the substance is used. The result is expressed as a percentage, as shown in equation 1.

Once this value is obtained, it is utilized to rank exposure to hazardous chemicals by comparing average chemical concentration levels throughout the working period with OEL-TWA values. (International Council of Chemical Associations, 2011).

$$\frac{\text{The concentration of the substance measured } \times 100\%}{OEL - TWA}$$

Figure 1. Equation 1

Then, the level of chemical exposure is divided into five levels as follows: no exposure, low, medium, high, and very high. These levels are determined based on the severity of hazardous chemicals that affect health, as shown in Table 2.

Risk Assessment

Risk assessment is a process of identifying potential hazards that may occur. Its function is to ensure that the risk control of the process and the operation are at an acceptable level. The key components of risk assessment are likelihood and severity. The values obtained from assessing likelihood and severity are then used to determine the risk level in the risk matrix, as illustrated in Table 3.

Acceptance Criteria

The risk level and the recommended acceptance criteria are selected based on the probability of health effects, as indicated in Table 1, Table 2, and

Table 3. The Risk Level Metrics Consider both Exposure Levels and Severity Levels

Severity Level	Exposure Level					Risk Level		
	(1)	(2)	(3)	(4)	(5)	Score	Result	Level
5	5	10	15	20	25	21-25	Very High	5
4	4	8	12	16	20	17-20	High	4
3	3	6	9	12	15	10-16	Medium	3
2	2	4	6	8	10	4-9	Low	2
1	1	2	3	4	5	1-3	Tolerance	1

Table 4. Risk Level – Definitions and Recommended Acceptance Criteria

Risk Level	Score	Recommended action
Very low	1 – 3	Risk reducing measures are not required
Low	4 – 9	Risk reducing measures can be implemented
Medium	10 – 16	Risk reducing measures should be implemented
High	17 – 20	Risk reducing measures must be implemented such as personal protective equipment provided, contingency plan and engineering control
Very high	21 – 25	Stop the operation immediately

Table 3 as above. The chosen criteria are outlined in Table 4 below. It is important to note that these acceptance criteria are proposed guidelines and may be subject to variation.

RESULT

Workplace Environment

Secondary data on work processes in the power plant process related to chemicals at a combined cycle power plant in Rayong Province, Thailand, including the water quality improvement process (Demin Water Analysis), the Cooling Tower water

Table 5. The Results of Chemical Hazards in Workplace Over Three Years

Chemical List	CAS No.	EC No.	UN	Location	Exposure Route	Employee Exposure	Monitoring Results			Unit	OEL-TWA Standard	Acceptance Criteria
							Year 2021	Year 2022	Year 2023			
Hydrogen Peroxide	7722-84-1	231-765-0	2015	Demin Water Plant Process	Inhalation	2	ND	ND	<0.08	ppm	1[1/2/3/4]	Pass
Sodium Hydroxide	1310-73-2	215-185-5	1823	Demin Water Plant Process	Inhalation	2	0.012	ND	ND	mg/m3	2[1/2/3/4]	Pass
Sulfuric acid	7664-93-9	231-639-5	1830	Demin Water Plant Process	Inhalation	2	ND	ND	ND	mg/m3	1[1],0.2[2],1[3],1[4]	Pass
Hydrochloric acid	7647-01-0	231-595-7	1050	Demin Water Plant Process	Inhalation	2	ND	ND	<0.05	ppm	5[1,3,4],2[2]	Pass
Sodium Hypochlorite	7681-52-9	231-668-3	1791	Cooling Tower	Inhalation	2	ND	ND	ND	mg/m3	-	Pass
Cadmium	7440-43-9	231-152-8	2570	Welding & Workshop	Inhalation	1	ND	ND	ND	mg/m3	0.005[1/3], 0.012	Pass
Chromium	7440-47-3	231-157-5	-	Welding & Workshop	Inhalation	1	ND	ND	ND	mg/m3	0.1[2],1[3],0.5[4]	Pass
Copper	7440-50-8	231-159-6	3089	Welding & Workshop	Inhalation	1	ND	ND	ND	mg/m3	0.2[2],0.1[3/4]	Pass
Lead	7758-97-6	231-846-0	2291	Welding & Workshop	Inhalation	1	ND	ND	ND	mg/m3	0.05[1/2/3/4]	Pass
Mercury	7439-97-6	231-106-7	2809	Welding & Workshop	Inhalation	1	ND	ND	ND	mg/m3	0.1[1/3], 0.025[2], 0.05[4]	Pass

Remark:

1 (Notification of the Department of Labor Protection and Welfare, Subject: The Concentration Limit of Hazardous Chemical, B.E.2560 (A.D.2017), 2017)

2 Recommendation of American Conference of Governmental Industrial Hygienists (ACGIH).(ACGIH ®, 2024)

3 Regulation of Occupational Safety and Health Administration (OSHA).(Occupational Safety and Health Administration (OSHA), 1970)

4 Recommendation of National Institute for Occupational Safety and Health (NIOSH).(National Institute for Occupational Safety and Health (NIOSH), 2013)

ND (non-detectable) means not detected or less than detection limit.

quality improvement process, and the equipment welding work process of the maintenance section, were studied. The employees have a full-time working period of 8 hours per day, during which they are exposed to hazardous chemicals in the work environment, including hydrogen peroxide, sodium hydroxide, sulfuric acid, hydrochloric acid, sodium hypochlorite, cadmium, chromium, copper, lead and mercury, Exposure of2-4 hours per day is classified as a frequency of contact at level 3, which corresponds to quite frequent exposure, involving contact 2 to 3 times per month (a few times per month).

Chemical Hazards Exposure

The concentration of chemicals to which employees are likely to be exposed for 2 to 4 hours per day, while working in the power plant process, water quality improvement department (Demin Water Analysis), Cooling Tower water quality improvement process, and the equipment welding work process of the maintenance section, was found to meet concentration levels and standards, as shown in Table 5. Hydrogen peroxide, sodium hydroxide, and hydrochloric acid were detected. The chemical concentration levels were compared to OEL-TWA, as shown in Table 6.

Severity of Chemical Hazards

Toxicity can be arranged in the following order: Hydrogen peroxide is classified as highly severe, indicating its corrosive nature. Brief exposure can cause corrosion to the eyes and digestive tract if ingested. Its vapors can severely irritate the respiratory tract. Ingestion can lead to excessive foaming, increasing the risk of choking and suffocation. Exposure may also result in the formation of oxygen bubbles in the blood, leading to shock. Prolonged or repeated exposure to vapors, either through inhalation or over an extended period, may result in chronic inflammation of the upper respiratory tract. Continued exposure over time may also affect the lungs. Additionally, this substance may impact hair and bleaching processes.

Table 6. The Results of Frequency of Exposure Rating into Account Magnitude of Exposure Rating

Chemical List	Employee Exposure	Magnitude of Exposure Rating (MR) (%OEL-TWA)	Frequency of Exposure Rating (FR)	Probability Rating
Hydrogen Peroxide	2	1 (8%)	3	3
Sodium Hydroxide	2	1 (0.6%)	3	3
Sulfuric acid	2	-	3	3
Hydrochloric acid	2	1 (1%)	3	3
Sodium Hypochlorite	2	-	3	3
Cadmium	1	-	2	2
Chromium	1	-	2	2
Copper	1	-	2	2
Lead	1	-	2	2
Mercury	1	-	2	2

Table 7. The Results of Chemical Exposure Risk Assessment

Chemical List	Exposure Level	Severity Level	Score Result	Risk Level	Risk Control Measurement
Hydrogen Peroxide	3	4	12	3	General obligations
Sodium Hydroxide	3	4	12	3	Role and responsibilities of the competent authority;
Sulfuric acid	3	4	12	3	employers, workers, and
Hydrochloric acid	3	4	12	3	suppliers
Sodium Hypochlorite	3	3	9	2	Operational control
Cadmium	2	4	8	2	Assessment of control needs and elimination of hazards.
Chromium	2	4	8	2	Personal protective equipment
Copper	2	4	8	2	Exposure Monitoring
Lead	2	4	8	2	Emergency Preparedness and response
Mercury	2	4	8	2	Engineering control

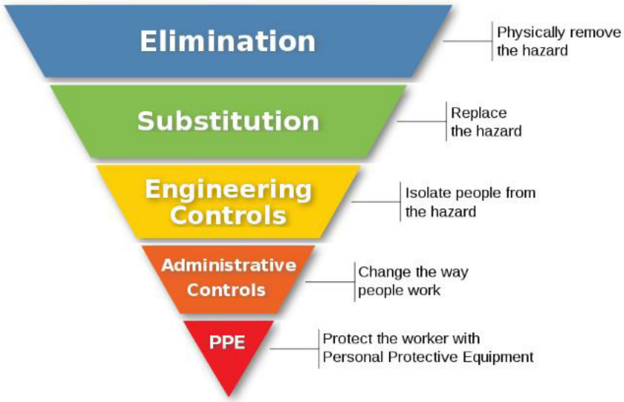

Figure 2. Hierarchy of Control

Sodium hydroxide inhalation can cause irritation and damage to the upper respiratory tract, resulting in symptoms such as sneezing, throat pain, or a runny nose. Severe exposure may lead to pneumonia and shortness of breath. Contact with the skin can cause severe irritation, burns, and blisters. Prolonged exposure to the substance may lead to carcinogenicity and other abnormalities, causing tissue destruction due to its corrosive effect.

Hydrochloric acid, upon exposure, can cause serious local effects when entering the body through various exposure channels. This substance can be absorbed into the body through inhalation. Health effects from short-term exposure: Skin exposure may result in frostbite-like damage. This substance is corrosive to the eyes. Inhalation can lead to symptoms resembling asthma. In severe cases, there may be signs of suffocation due to swelling of the throat. High concentrations of inhalation may cause pneumonia. Initial exposure often results in visible effects on the eyes and respiratory system due to the corrosive nature of this substance. Health effects from prolonged or repeated exposure: Repeated or prolonged inhalation of this substance may result in dental effects, including erosion. It can also impact the upper respiratory tract and lungs, leading to chronic inflammation and reduced lung function. Additionally, concentrated inorganic acid aerosols are known to be carcinogenic to humans. However, for chemicals whose concentrations cannot be measured in the working atmosphere, such as sulfuric acid, sodium hypochlorite, cadmium, copper, lead, and mercury, there are still hazards that require continuous monitoring as mandated by law to ensure the safety of employees exposed to such chemicals.

Health Risk Assessment

Based on the risk matrix, the risk assessment results for hydrogen peroxide, sodium hydroxide, sulfuric acid, and hydrochloric acid were classified as exceeding acceptable levels for employee health, being higher than level 1 as shown in Table 7.

DISCUSSION

Measurements of chemicals in the working environment over the past three years showed similar values, with average concentrations below 50% of the OEL-TWA limits for all 10 substances. However, chemicals in the atmosphere must be monitored even if they do not exceed the standards set by requirements (Thailand institute of Occupational Safety and Health (Public Organization), 2021)

Assessing health risks from exposure to chemicals among employees in the power plant production process considers the likelihood of exposure and the severity of the chemicals affecting the health of those exposed, with a full-time working period of 8 hours per day (Chaiklieng, Suggaravetsiri and Autrup, 2019) . However, review of worksite monitoring data indicates that exposure to hazardous chemicals is likely between 2-4 hours per day, as, based on the Ministry of Industry's frequency of contact criteria from B.E.2555 (A.D.2012), frequent contact with chemicals in the production process is identified (Notification of Ministry of Industry: Thailand Industrial Standard for Chemical Health Risk Assessment for Industrial Worker B.E. 2555. (A.D. 2012), 2012).

Among the ten chemicals studied, we focused on those measurable in the work atmosphere (hydrogen peroxide, sodium hydroxide, sulfuric acid, and hydrochloric acid) due to their toxicity found that hydrogen peroxide appears as a liquid. It can be absorbed into the body through inhalation, ingestion, and skin contact. Short-term exposure can cause corrosion to the eyes, skin, and respiratory tract. Exposure may lead to the formation of oxygen bubbles in the blood, resulting in shock. Long-term or repeated exposure, particularly through chronic inhalation of the vapor, may induce chronic inflammation of the upper respiratory tract.

Sodium hydroxide appears as a liquid and its solution in water is a strong base. It can cause effects through all routes of exposure. Short-term exposure can lead to corrosion of the eyes, skin, and respiratory tract. Long-term or repeated contact with the skin may result in dermatitis (International Labour Organization, 2021; National Institutes of Health (National Institutes of Health), 2024).

Sulfuric acid is an odorless, colorless, oily hygroscopic liquid. It poses chemical dangers as it decomposes when heated, producing toxic gases including sulfur dioxide. It has serious local effects through all routes of exposure. Short-term exposure is highly corrosive to the eyes, skin, and respiratory tract, and ingestion can be corrosive. Exposure may also lead to asphyxiation due to throat swelling. Long-term or repeated skin contact may cause dermatitis, while inhalation may affect the lungs (International Labour Organization, 2021; National Institutes of Health, 2024).

Hydrochloric acid is a colorless, compressed liquefied gas with a pungent odor. Its solution in water forms a strong acid and reacts violently with bases and oxidants, exhibiting corrosive properties. Short-term exposure may result in rapid evaporation of the liquid, leading to frostbite. The substance is corrosive to the eyes, skin, and respiratory tract, and inhalation of the gas may trigger asthma-like reactions (RADS). Long-term or repeated inhalation exposure may cause dental effects, such as tooth erosion, and affect the upper respiratory tract and lungs, potentially leading to chronic inflammation and reduced lung function (International Labour Organization, 2021; National Institutes of Health, 2024).

Chemical exposure risk assessment considers both the frequency of exposure and the inherent severity of the chemicals (toxicity) (Papadopoli *et al.*, 2020; Putri and Nuruddin, 2022). This study found risk levels to be low to medium, with potential for higher risks from highly hazardous chemicals like carcinogens, corrosives, and irritants. The severity of health effects further elevates the risk (International Labour Organization, 2021; National Institutes of Health, 2024;Rai *et al.*, 2020).

The recommendation for controlling chemical exposure must adhere to the hierarchy of controls employed to eliminate or minimize exposure to chemical hazards. There are five categories in the hierarchy, with control methods at the top potentially being more effective than those at the bottom as shown in Figure 1 (Ayuningtyas and Nasri, 2021; Horn *et al.*, 2022).

A limitation of this study, relying on secondary data, is the absence of employee symptom history information. This lack of data on symptom experiences among workers exposed to these substances hinders a comprehensive evaluation of their health risks. Future studies should prioritize collecting this crucial information.

CONCLUSION

From the study, it was found that even though the results of the workplace environment measurements met the criteria required by law, upon considering the results of the health risk assessment that consider both the probability of exposure and the severity of the impact, workers exposed to chemical hazards in the power plant are at risk of various health problems, influenced by the nature and concentration of the chemicals, exposure duration, and the effectiveness of protective measures. Common health issues include respiratory conditions such as asthma and bronchitis, skin and eye disorders like dermatitis and chemical burns, and neurological effects, including headaches and cognitive impairments. Prolonged exposure can lead to systemic toxicity affecting internal organs, carcinogenic effects increasing cancer risk, and reproductive issues such as infertility or congenital disabilities. Acute poisoning from high-level exposure may result in severe symptoms like seizures or respiratory failure, while mutagenic effects can cause genetic mutations and hereditary health risks. These risks highlight the critical need for effective safety protocols, including personal protective equipment (PPE), proper ventilation, health monitoring, and worker training in handling hazardous chemicals. Therefore, exposure surveillance through industrial hygiene monitoring should be organized, especially in areas with hazardous chemicals, particularly highly hazardous chemicals such as carcinogenic and mutagenic substances. Assessing health risks related to these highly hazardous chemicals among individuals exposed to chemicals in the workplaces is required by law.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interests regarding the publication of the paper.

AUTHOR CONTRIBUTION

The authors confirm contribution to the paper as follows: study conception and design: Somboon Chaiprakarn, Chanakarn Sakulthaew; data collection: Somboon Chaiprakarn, Chanakarn Sakulthaew; analysis and interpretation of results: Somboon Chaiprakarn, Mongkol Ratcha; draft manuscript preparation: Somboon Chaiprakarn, Panudech Saengseedam. All authors reviewed the results and approved the final version of the manuscript.

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