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HAZARD IDENTIFICATION, RISK ASSESSMENT AND RISK CONTROL (HIRARC) ON LABORATORY WASTE DISPOSAL IN CHEMISTRY LABORATORY

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Abstract

The academic laboratory used for teaching and learning often generates many types of hazardous wastes. It is crucial to have proper laboratory waste disposal management to enhance safety and minimize the environmental effect in the academic laboratory. The objective of this study was to determine the risk associated with waste disposal activity in the chemistry laboratory of Universiti Teknologi MARA Cawangan Pulau Pinang based on the Hazard Identification, Risk Assessment and Risk Control (HIRARC) model. Five chemistry laboratories have been selected for this study. The first step involved hazard identification conducted through workplace inspections and observation. Each hazard was assessed, and the risk was calculated based on the likelihood of occurrence and severity of harm. Several risk control options to reduce or eliminate the risk were proposed. The HIRARC model identified thirty critical hazards in the waste disposal process, with 63.3% classified as low risk and the remaining 33.3% and 3.3% as medium risk and high risk, respectively. Therefore, the waste disposal process can be deemed hazardous to laboratory personnel. The main hazards were chemical (63%), physical (17%), ergonomic (13%), and biological (7%). The high-risk activities were associated with the chemical hazard. Engineering control, administrative control, and personal protective equipment (PPE) are among the control measures presented in this study. The control measures and corrective actions could be applied to improve the safety aspect in the laboratory and prevent accidents.

Keywords: academic laboratory, laboratory waste disposal, hazard, risk assessment, HIRARC

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Introduction

An academic laboratory assists in most activities involving students, lecturers, and laboratory staff during the teaching and learning process (Chowdhury, Alam, and Mustary 2019). A large amount of laboratory waste is produced during these activities. In general, laboratory waste can be categorized into chemical, biological, clinical, and electrical waste, and it poses a direct threat and various hazards to laboratory users and the environment. Thus, it is essential to practice a proper waste management system, including safe disposal of waste and proper waste handling and storage, which could improve the safety aspect in the laboratory. Laboratory waste is commonly disposed into recycling trash, chemical or biohazard waste containers, glassware disposal boxes, or sharp containers, depending on the type and characteristics of the wastes.

The leniency toward laboratory safety frequently causes laboratory accidents in academic institutions compared to industrial laboratories (Sarah Ismail et al. 2015). These include accidents related to waste disposal activities. The University of Tokyo reported 78 chemical disposal-associated accidents from April 2004 to March 2012, where 87.2% of the cases happened either in laboratories or during the transportation of chemical wastes from laboratories to the calling-in-point (Karima 2013). On March

21, 2019, a massive explosion at Tianjiayi Chemical Co. Ltd., Xiangshui, was reported with severe casualties of 78 deaths, 640 injuries, and property damage. This incident was speculated from the heat accumulation on nitrate waste stored for more than seven years in an old warehouse due to tight waste stacking and poor ventilation (Yang et al. 2020). According to the investigation done by Zhu et al. (2020) on 100 different laboratory accidents occurring from 2001 to 2018, human factors such as improper and careless operation, and violation of operating rules, are the leading cause of these circumstances. This finding agrees with a report on 95 laboratory accidents in the colleges and universities in China from 2010 to 2015, which stated the violation of experimental operating rules and careless experimental operation as the significant inducing factors. Due to the severe consequences of laboratory accidents on an organization, it is of utmost importance to identify the hazards from the waste disposal process that could lead to accidents in a laboratory. Among the appropriate methods to identify and assess these hazards is the Hazard Identification, Risk Assessment and Risk Control (HIRARC) model, which is commonly implemented at workplaces to manage the safety and health of workers.

A HIRARC model involves four consecutive steps of work activities classification, hazard identification, risk analysis, and control measures determination (DOSH 2008). Hazard identification can help identify hazards at a workplace and determine the necessary corrective actions to control them. On the other hand, risk assessment provides a means to identify and rank the risks and provide information on their severity and nature (DOSH 2008). According to the control hierarchy, risk control can be broken down into five approaches: elimination, substitution, engineering control, administrative control, and personal protective equipment (PPE). A combination of control measures may be practical to manage the hazard efficiently. Numerous studies have been carried out on the hazards in the industry, such as hydroelectric power generation plant (Saedi, Thambirajah, and Pariatamby 2014), power plant (Ahmad et al. 2016), corrugated box manufacturers (Barahim 2010), and boiler division (Ramdan et al. 2017) based on the HIRARC model. However, the HIRARC model is rarely applied to identify the waste disposal process in academic laboratories. Thus, this study aims to identify the hazards associated with the waste disposal process at selected academic laboratories using the HIRARC model and propose control measures to reduce or eliminate the identified risks to a tolerable level.

Methods

The HIRARC model was employed in this study to identify and manage the hazards associated with the waste disposal process in five chemistry laboratories in Universiti Teknologi MARA Cawangan Pulau Pinang. The HIRARC method uses a sequence of hazard identification, risk assessment, and risk control, which are discussed in detail in the following sections.

Hazard Identification

Hazard identification is an evaluation process conducted on any situation that may induce harm to its surroundings. The hazard identification of the waste disposal process in the chemistry laboratory was carried out through workplace inspection and observation. The workplace inspection was conducted at chemical laboratories using a hazard identification checklist consisting of five parts covering the waste collection, storage, waste container management, documentation, and training. The checklist effectively evaluated the hazards during the waste disposal process. A briefing session by the laboratory personnel from each laboratory on the process and procedures for waste disposal was performed to understand further the process and current practice.

Risk Assessment

A risk assessment is a process of determining the magnitude of a risk, which is then used to assess its tolerance level. The following equation can be used to calculate risk.

Risk (R) = Likelihood (L) x Severity (S) (1)

Where likelihood (L) refers to the likelihood of occurrence for a specified hazardous event, and severity (S) refers to the consequences of the specified hazardous event. Table 1 shows the level of risk likelihood.

Table 1: Levels of risk likelihood

LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazards/event being realized	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might occur sometime in future	3
Remote	Has not known to occur after many years	2
Inconceivable	Is practically impossible and has never occurred	1

Table 2 shows the different hazard severity categories (S), commonly used as a guideline to develop a hazard analysis or risk assessment matrix (DOSH 2008).

Table 2: Hazard severity categories

SEVERITY (S)	EXAMPLE	RATING
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality and major property damage if a hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible	Minor abrasions, bruises, cuts, first-aid type injury	1

Table 3 shows the risk values determined using equation (1) represented in a two-dimensional matrix chart. The risk matrix chart categorizes risk as high, medium, or low (Abdul Wahab et al. 2020). High risk requires immediate actions to control its hazards, while a medium risk requires a planned approach to control, where a temporary measure is sometimes needed. On the other hand, a low risk may be acceptable and does not require any immediate actions.

Table 3: Risk matrix chart

	Severity (S)				
Likelihood (L)	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

High Medium Low

Risk Control

Risk control initiates control measures that help prevent workplace accidents and injuries. Elimination, substitution, engineering control, administrative control, and personal protective equipment (PPE) are among the control measures implemented.

Result and Discussion

The waste disposal process in the chemistry laboratory involves four main activities: collecting waste from the laboratories, transportation of waste to temporary storage areas, transport of waste to storage houses, and housekeeping. The generated wastes from teaching and learning activities and research are collected in waste bottles at the end of each laboratory session. These wastes are then transported to the temporary storage areas in the laboratories, where the waste storage is sealed every week or once occupied. The waste was then transported to the waste storage house by two laboratory personnel weekly. Proper handling of wastes during their transportation is important to ensure no spillage occurs during the transportation process. Finally, housekeeping is performed to maintain the cleanliness and safety of the laboratories, temporary storage areas, and waste storage houses.

Based on the workplace inspection, the main concerns identified in the laboratory waste disposal process were improper or no labelling of wastes, combined storage of incompatible materials, inappropriate or no segregation of wastes, improper sealing of waste bottles, and excessive on-site waste storage. Most waste disposal storage areas were not equipped with secondary containment that acts as a collector of any spilt hazardous materials from waste bottles. The storage house also has minimal space for container handling by the workers, and some wastes were kept in the storage houses for more than one year. These factors may contribute to the hazards in the waste disposal process in the academic laboratories. From this study, thirty critical hazards related to waste disposal were identified. The identified hazards with the risk level and recommended control measures are shown in Table 4.

Table 4: Identified hazards with the risk level

HAZARD IDENTIFICATION		RISK ANALYSIS			RISK CONTROL
	HAZARD	LIKELIHOOD	SEVERITY	RISK	RECOMMENDED CONTROL MEASURE
Waste collection from laboratory activites					
1	Exposure to an unknown chemical	2	2	4(L)	Wear PPE at all times
2	Splashes of chemical	2	2	4(L)	Use funnel and wear PPE
3	Spillage of chemical	3	2	6(M)	Use funnel and wear PPE and prepare a secondary containment
4	Sharp injuries from broken glassware	4	1	4(L)	Wear PPE and implementing safe procedure for sharp waste disposal
5	Exposure to bacteria and virus	1	3	3(L)	Wear PPE at all times
6	Inhalation of chemical fumes	1	4	4(L)	Perform in a fumehood
7	Contact with chemical	3	2	6(M)	Wear PPE at all times
Transportation of waste to a temporary storage area					
8	Splashes of chemical	3	2	6(M)	Ensure all containers are sealed and closed. Containers be filled with maximum 90%
9	Spillage of chemical (not properly sealed)	3	2	6(M)	Ensure all containers are sealed and closed. Containers be filled with maximum 90%
10	Contact with chemical	2	3	6(M)	Wear PPE at all times

11	Musculoskeletal injuries or backpain from awkward bending posture (lifting or carrying a load)	3	2	6(M)	Lift load properly and pay attention to posture. Reduce weight by having two persons to carry loads
12.	Slip, trip and fall (no second containment)	2	1	2(L)	Prepare second containment to avoid spillage to floor
13	Incompatible chemical reaction (no segregation of waste)	1	4	4(L)	Ensure correct and up-to date waste label. Store incompatible away from each other
14	Slip trip and fall – obstruction of the walkway	1	1	1(L)	Good housekeeping practice and safety audit and workplace inspection
15	Inhalation of chemical fumes	1	4	4(L)	Wear proper PPE. Ensure proper ventilation and use of exhaust fan
Transportation of waste to the storage house					
16	Splashes of chemical	1	2	2(L)	Ensure all containers are sealed and closed. Containers be filled with maximum 90%
17	Spillage of chemical	2	2	4(L)	Ensure all containers are sealed and closed. Containers be filled with maximum 90%. Provide second containment
18	Inhalation of chemical fumes	1	3	3(L)	Ensure all containers are sealed and closed. Wear PPE
19	Muscular pain or back pain from lifting or carrying heavy loads	3	2	6(M)	Lift load properly and pay attention to posture. Reduce weight by having two persons to carry loads
20	Muscular pain or back pain from pushing and pulling trolley - heavy loads	3	2	6(M)	Lift load properly and pay attention to posture. Reduce weight by having two persons to carry loads
Housekeeping (Temporary storage area/ storage house)					
21	Spillage of chemical (due to improper stacking)	2	2	4(L)	Prepare second containment to avoid spillage to floor. Ensure all containers are sealed and closed. Containers be filled with maximum 90%
22	Incompatible chemical reaction (no segregation/ incomplete label)	1	4	4(L)	Ensure correct and up-to date waste label. Store incompatible away from each other
23	Inhalation of chemical fumes (no exhaust fan)	1	4	4(L)	Ensure proper ventilation and use of exhaust fan
24	Slip, trip and fall (no second containment)	2	2	4(L)	Good housekeeping practice and regular workplace inspection
25	Exposure to bacteria and virus (no segregation between bio-waste)	1	4	4(L)	Correct labelling and use of PPE
26	Slip trip and fall (obstruction of walkway)	3	2	6(M)	Good housekeeping practice and regular workplace inspection
27	Spillage of chemical (not properly sealed)	2	2	4(L)	Ensure all containers are sealed and closed. Containers be filled with maximum 90%. Provide second containment

*L: low; M:	28	Chemical reaction due to the use of incompatible container	1	3	3(L)	Ensure correct and up-to date waste label. Store incompatible away from each other
	29	Waste accumulation of more than 1 year	3	5	15(H)	Ensure correct and up-to date waste label. Conduct regular scheduled waste disposal to avoid excessive waste on site.
	30	Muscular pain or back pain from lifting or carrying heavy loads	3	2	6(M)	Lift load properly and pay attention to posture. Reduce weight by having two persons to carry loads

medium; H: high

The hazards were classified into three risk levels; high, medium, and low. Figure 1 shows the percentages of risk levels in the waste disposal process in the chemistry laboratories, with low risk accounting for 63.3% of total risk, followed by medium risk and high risk at 33.3% and 3.3%, respectively. The findings indicated that the waste disposal activities in the chemistry laboratories are potentially hazardous to laboratory personnel, and control measures should be taken to protect them from hazardous situation.

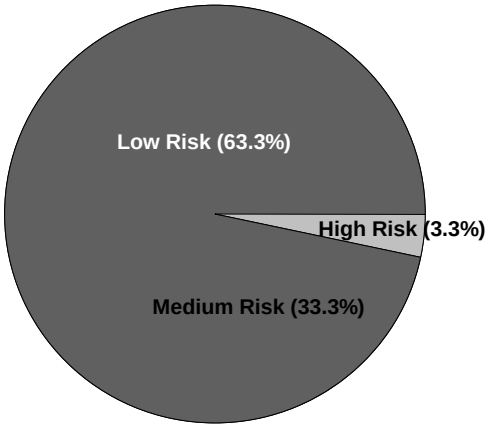

Figure 1. Risk levels of hazards on the waste disposal process at the chemical laboratories

Figure 2 illustrates the various hazards identified in the waste disposal process at the academic laboratories, including chemical, biological, physical, and ergonomic hazards. Chemical hazard is the most common hazard, accounting for 63% of the total hazard, followed by physical hazard (17%), ergonomic hazard (13%), and biological hazard (7%). The high percentage of chemical hazards could be attributable to the heavy usage of chemicals in the chemical laboratory.

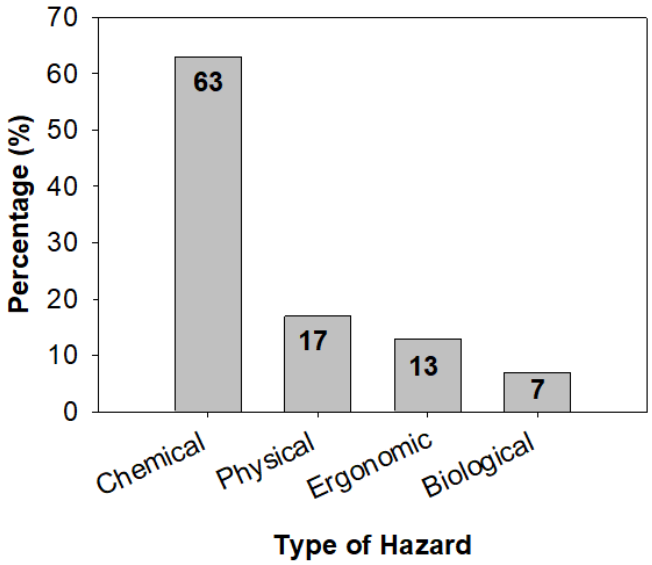

Figure 2. Types of hazards in the waste disposal process at the selected academic laboratories

The risk level classification for each type of hazard is presented in Figure 3. 68.4% of the chemical hazard was classified as low risk, 26.%3 as a medium risk with the remaining 5.3% as high risk. For physical hazards, 80% of the physical hazard was a medium risk, followed by 20% low risk. All biological hazards were considered low risk and ergonomic hazards as medium risk. The high risk chemical hazard was for the waste accumulated for more than 1 year in high quantity and it is of grave concern as it could lead to a severe accident.

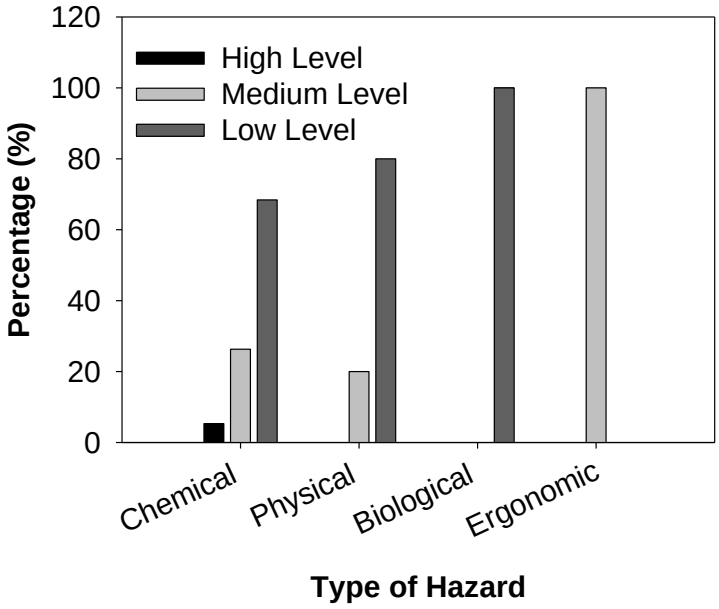

Figure 3. The risk levels for the main hazards in the waste disposal process at selected academic laboratories

During waste disposal, the laboratory staff comes into contact with different chemicals. Improper handling of chemical wastes can greatly inflict adverse health effects such as skin irritation, respiratory problem, and in some cases, even death. Inhaling contaminated air or direct contact with biological waste can cause serious infections. Meanwhile, inhaling chemical fumes may induce respiratory

irritation, upper chest pain, and dizziness. During the waste transportation into the temporary storage areas or storage houses, the laboratory staff is widely exposed to sharp objects that could cause physical injuries through sharp pricks or cuts. Other than that, bending posture and lifting load are the common hazards identified during the segregation and transportation of wastes, leading to back pain and musculoskeletal disorders. Focus on the concerned areas, precisely the high and medium risk, is required so that proper control measures can be applied to eliminate or reduce the risk and ensure all activities are carried out in compliance with the safety requirements. These hazards could be appropriately managed by applying control measures of elimination, substitution, engineering, administrative, or personal protective equipment (PPE). The usual practice applied for risk control in academic laboratories are engineering control, administrative control and PPE (Abdul Wahab et al. 2021)

Engineering control could be incorporated to avoid inhaling chemical fumes and contaminated air, such as using local exhaust ventilation (LEV). LEV could remove vapours, dust, gases, and fumes through the hood during the laboratory waste collection process. Regular inspections of the LEV were carried out in the chemical laboratory to ensure its effectiveness. The local exhaust fan was installed in the storage house and is in the process of installing it in the temporary storage area. This exhaust fan could provide good ventilation during storage and help protect the laboratory personnel from harmful vapour gases. The laboratory management provides secondary containment for the waste container in the storage house and temporary storage area as it could help minimize the spillage spread. Sawdust was also provided to be used in case of spillage.

Training is one of the administrative controls that could reduce the hazards in the waste disposal process. The safety and health committee of Universiti Teknologi MARA Pulau Pinang has conducted various training in 2021 related to laboratory safety for laboratory personnel to provide them with the necessary knowledge on laboratory safety and efficient waste management within their laboratories. The committee has conducted a webinar on scheduled waste disposal and packaging, labelling and storage of scheduled waste to address the issue of waste disposal. The committee also organized a webinar on ergonomics, handling of chemicals hazardous to health and HIRARC to expose laboratory personnel to the current issues and practices related to the topics and educate them on avoiding long-term health effects from workplace hazards.

In compliance with the requirement, a complete Safety Data Sheet (SDS) for all chemicals was provided in all laboratories to help effectively distinguish its potential hazards. An e-chemical register known as CHEM-Reg has been created that incorporates the SDS to ensure the SDS is easily accessible to all laboratory users. The CHEM-Reg, which contains 3 sections, helps provide information on the chemicals in the SDS and helps track the chemicals easily. All laboratories are in the process of implementing and applying the CHEM-Reg with the hope that it will significantly assist in chemical management. The existing standard operating procedure (SOP) for waste disposal must be reviewed to enhance the process, further reflect the current practices and protect the laboratory personnel from the said hazard. Once issued, the SOP must be followed to provide a proper and consistent practice on waste disposal. HIRARC of the waste disposal process must be documented appropriately and constantly reviewed to enhance the safety measure in the waste disposal process.

Administrative control through adequate housekeeping is essential to avoid physical hazards such as slips and falls. The laboratory management has issued all laboratories to prepare a proper instruction and housekeeping schedule. The main concern is ensuring that all walkways, including the walkway to the safety shower and eyewash, should be clear from obstructions. The laboratory personnel must assure that the waste containers must be compatible and properly labelled to prevent unwanted chemical reactions that might incur an explosion or fire. A standardized label was also provided to label the waste in the laboratories. This label must include all the required information, including the date of waste generation. This action is critical to ease waste segregation and prevent extended waste storage of more than 180 days.

The safety committee conducted a safety audit in the chemistry laboratory to ensure that all necessary steps and actions had been taken. Findings from the safety audit have been presented to the laboratory management for corrective action. This safety audit helped to improve the safety aspect in the laboratory. The laboratory management was also advised to conduct a self-audit from time to time to check for compliance with the rules and requirements. Safety signage has also been placed in the designated areas to improve safety and awareness.

The last control measure is the usage of PPE among laboratory personnel. All laboratory personnel were given the PPE (a laboratory coat, safety glasses, gloves, and respirator). They are required to use them correctly according to the standard guidelines. However, there are still a few who did not wear the PPE. A reminder has been issued to the staff, and the laboratory management should take the responsibility to ensure that all staff wear the PPE during work. Training on the correct use of PPE has been proposed to the management and will take place soon.

The risks associated with the waste disposal process could be eliminated or reduced by implementing the abovementioned control measures. This risk assessment is expected to establish positive changes in the working practice of the waste disposal process. Appropriate corrective actions should be taken to improve the overall process, and the risk assessment should be periodically reviewed to ensure the effectiveness of the control methods in eliminating risks.

Conclusion

Implementing the HIRARC study as a routine practice in all academic laboratories is necessary to identify the potential high-risk hazards and apply proper control measures to eliminate or reduce the risk earlier. In this study, 30 hazards were identified in the waste disposal process at the chemistry laboratories. Most of the hazards were classified as low risk, followed by medium and high risk. Based on the current research findings, the laboratory staff can consider the waste disposal process as potentially hazardous. However, some control measures have been taken and regularly reviewed to ensure its effectiveness. These include engineering control, administrative control, and PPE use. Training or workshop regarding chemical waste management should also be frequently organized to ensure proper laboratory waste disposal is practiced according to the standard guidelines.

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