Journal of Energy and Safety Technology

JEST

RESEARCH ARTICLE Open Access

Concerns of Airborne Ammonia in Ice-Production Facilities: Enhancing Protection Of Workers In Malaysia

Hazlina Yon

Department of Occupational Safety and Health, Malaysia

*Corresponding author:hazlina@mohr.gov.my

Article History

Received:December 26, 2022 Receivedin revised form:January 31, 2023 Accepted:January 31, 2023 Published: February 9, 2023

Abstract

Audit findings conducted by the Department of Occupational Safety and Health from 2010 till 2018 at one hundred and forty-two (142) ice-production facilities throughout Malaysia, found that presence of ammonia can be detected easily throughout the ice factories and low level of occupational safety and health awareness was found among the owners. This study aims to determine profile of ammonia concentration in the layout of ice-production facilities which can contribute to significant health risk to its workers. The study has been conducted for eight months from September 2021 till May 2022 in four different zones in West Malaysia. Thisstudy is using both direct reading instruments such as a high performance multigas analyzer integrated with Fourier Transform Infrared (FTIR) and a Multirae data analyzer to measure ammonia concentration in thirty-eight ice-production facilities. Ammonia measurements confirmed that ammonia is detected at various locations in the factory layout. It is found to be localized and concentrated at the machine room followed by machine room combined with production room. Both instruments seem to show similar trend which validate the profile obtained for ammonia.The study also seeks to find a correlation between the compliance of these facilities with the Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) (USECHH) Regulations 2000 and compliance with the Guideline of Safe Management of Ammonia Refrigeration System 2020. Pre and post audits based on ammonia guideline were also conducted to identify any gap. It was found that the results obtained for the USECHH compliance, ammonia compliance either pre or post audits were not positively correlated. This finding emphasizes that there is still a lack of commitment from these ice-production facilities even after the visits by authorities. Comparison between the data ammonia measured and the degree of compliance using ammonia guideline were also made. The results obtained emphasize that there were no strong correlation between the data measured and the degree of compliance.This study provided suggestions, recommendations, measures and future measures to be taken to boost compliance with the USECHH Regulations. Future research with risk modelling of ammonia leakages could also be ventured into. Recommendations were also suggested for employers to improve or redesign their layout of the ice-production facilities based on these measurements.

Keywords: Ammonia profiling, compliance enforcement, ice-production facilities, lack of commitment, USECHH compliance.

1.0 INTRODUCTION

Ammonia is widely used in chemical and food industry as a common industrial gases. About 90 percent of ammonia produced is used in fertilizer, to help sustain food production for billions of people around the world. Ammonia emerges as an alternative to chlorofluoro carbon-based refrigerants and hydrofluoro carbon-based refrigerants. Ammonia is colorless, toxic and flammable chemical which is often stored under a certain pressure in the liquid form. Ammonia also has a distinctive odour which is detectable at low concentration. Even at low concentrations, ammonia can be irritating to eyes, skin and breathing passages. Various research highlighted about the leakage of equipment (pressure vessels, tanks or pipelines etc.) containing liquid ammonia was due to various reasons, such as corrosion, welding defects, lax sealing, valve damage and operational errors. These leakages cause casualties and environmental damage (Chen, S.N., Sun, J.H., Chu, G.Q., 2007).

Data from Chemical Information Management System (CIMS) (DOSH, 2020) indicates an increasing trend of the number of chemical suppliers in Malaysia. Figure 1 illustrates the increasing trend of the number of chemical suppliers in Malaysia from 2015 to 2020. The increasing trend scenario of total number of suppliers reflects that an influx of incoming chemicals into Malaysia is dynamic and is also largely depends on inventory submission from suppliers into the CIMS platform. Ammonia on the other hand, shows a fluctuating trend as depicted in Figure 2. Total volume of ammonia supplied is the highest in 2018, yet shows a decreasing trend in 2019 and 2020 (DOSH, 2020). This could possibly be due to the world is plagued with pandemic Covid-19 and all economies are affected including Malaysia. Only certain essential services were allowed to be in operation during the beginning of the pandemic which has affected Malaysia since March 2020.

Many accidents involving ammonia have been reported in the media. Figure 3 illustrates the trend of ammonia incidences for the past decade in Malaysia. More than 315 individuals including workers and nearby residents were affected by the incidences. These incidences also caused ten deaths cumulatively.

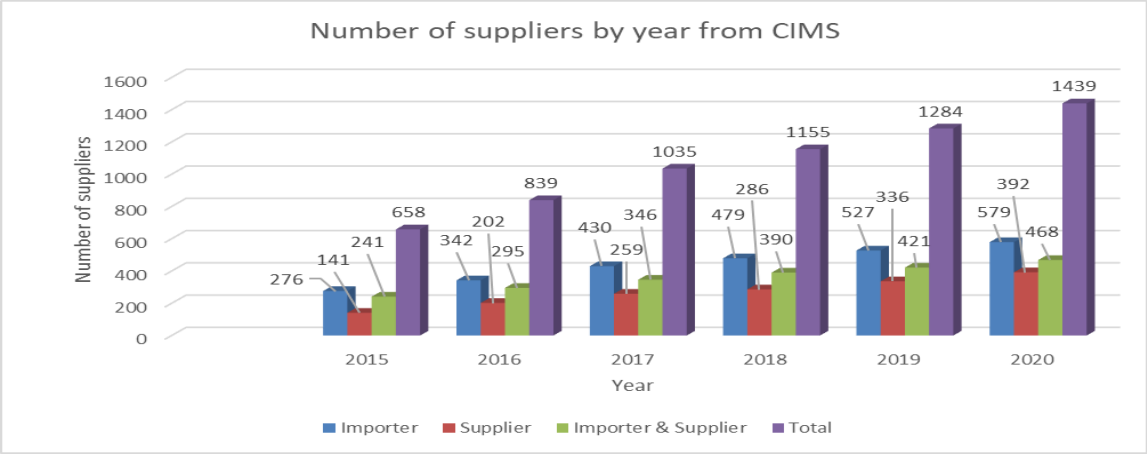

Figure 1: Increasing trend of total number of chemical suppliers in Malaysia from 2015 to 2020.

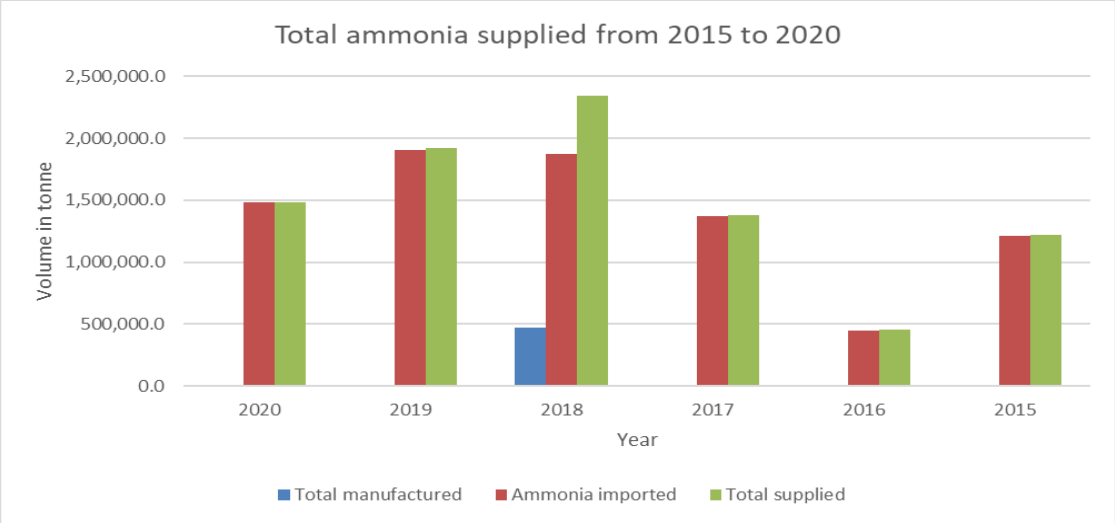

Figure 2: Fluctuating trend of volume of Ammonia supplied in Malaysia from 2015 to 2020.

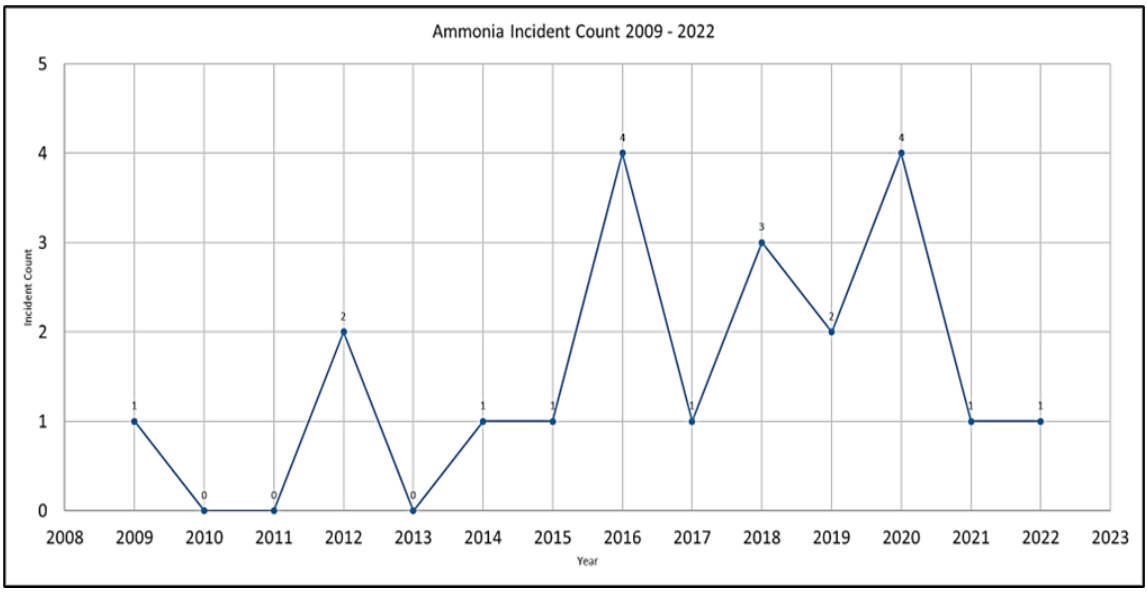

Figure 3: Fluctuating trend of Ammonia incidences in Malaysia from 2009 to 2022.

There were a total of twenty-one workplaces involved with these incidences from Figure 3. It was found that other types of manufacturing using ammonia as refrigerants represent majority of the incidences. The pie-chart in Figure 4 shows incidences related to exposure to ammonia as refrigerant. About 43% of the incidences occurred in ice production facilities throughout all states in Malaysia. Most of these incidences were due to pipeline leakage and lack of safety and health awareness on ammonia management (MHI, Melaka Hari Ini, 2020).

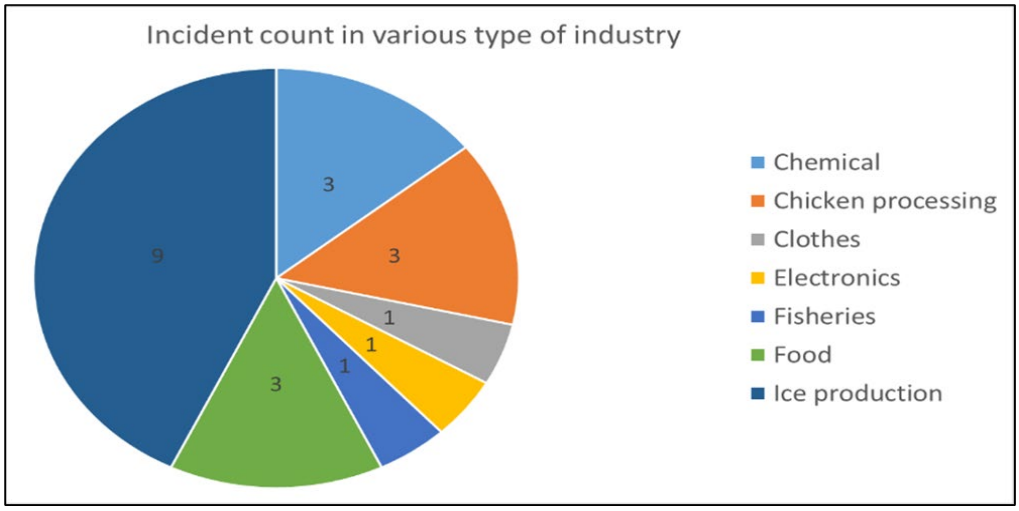

Figure 4: Fluctuating trend of ammonia incidences in Malaysia from 2009 to 2022.

Accidental ammonia releases cause injuries and death to employees, emergency response personnel, and people in surrounding communities. This is due to its physical properties. Anhydrous ammonia and ammonium hydroxide are two types of ammonia commonly used in industry. Ammonium hydroxide is formed when ammonia gas is dissolved in water. Anhydrous ammonia is very corrosive, and exposure to it may result in chemical-type burns to skin, eyes, and lungs. It may also result in frostbite, since its boiling point is -28ºF.

According to an analysis of hazardous chemicals accident in China between 2006 and 2017, it was found that compressed or liquified gases are the most commonly involved chemicals in hazardous chemical accidents in China (Zhao, L.J, et. al, 2018). While another study in India showed that a leakage occurred due to backpressure in one of hose of the fittings in the ammonia refrigeration system. It was also found that there was no self-contained breathing apparatus provided and maintained in the factory, no emergency response preparedness and no emergency response plan to tackle incidences such as ammonia accidental leakages. There was also no provision of preventive measures like water sprinkler arrangement around the compressor room to avoid any dispersion of ammonia gas from the compressor room to the outside (Bhattercharjee G., S. Bhattacharya, R.K. Gangopadhyay & S.K. Das, 2012).

Having knowledge of hazards of ammonia with its characteristics and the refrigeration system helps to mitigate and prevent further damage to the property and environment in the vicinity of the ice-production facilities. A basic ammonia refrigerant system usually consists of four components, evaporator; compressor; condenser; and reducing valve and is presented in Figure 5. Other components such as oil separator, intercooler, liquid receiver, surge drum and liquid pumps are commonly found. The useful refrigeration is produced at the evaporator where the liquid ammonia at low pressure, low temperature, takes in heat and vaporizes. This vapour is removed by the compressor, which in compressing it, raises the temperature from below to above ambient temperature. The hot compressed gas gives up the heat by condensing to a liquid in the condenser. The high-pressure liquid then passes through the pressure-reducing valve to the evaporator. At the valve, the liquid is cooled as some vapour flashes off. The remaining liquid is available for use in the evaporator. In practice other components like oil separator removes suspended oil carried over from the compressor and either returns it to the system or holds it for draining in some way (Department of Occupational Safety and Health, 2022).

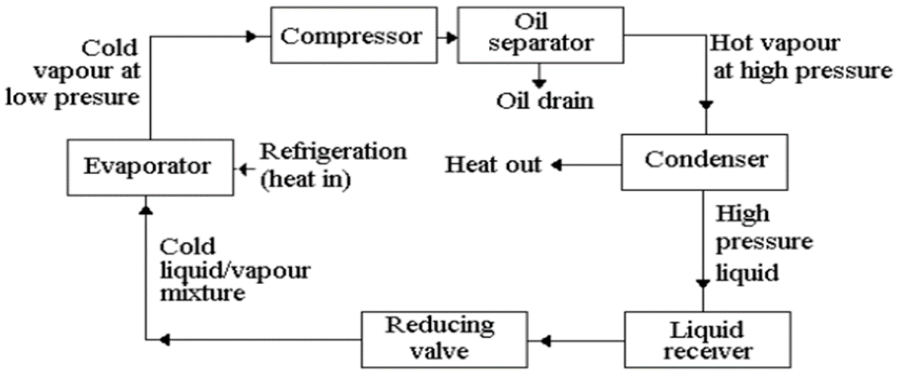

Figure 5: Simple Flow Diagram for Ammonia Refrigeration System.

The objectives of the study are to identify profiles of ammonia concentration in the ice-production facilities during its operation and to determine its compliance with the USECHH Regulations 2000 and its compliance with the Guideline of Safe Management of Ammonia Refrigeration System 2020. The results obtained could lead to identification of potential leakages or potential point of release of ammonia in these facilities, hence can assist industries to redesign their layout and to understand their status of occupational safety and health (osh) compliance. This study will be using a high performance multigas analyzer integrated with FTIR technology to identify and to map ammonia level profiling for selected ice-production facilities in Malaysia. Data gathered will be captured from the tablet of the analyzer and will be analysed. These data will also be used to compare with the data gathered in 2022 for the USECHH compliance, and the data gathered in 2022 based on ammonia audit checklist from the Guideline On Safe Management of Ammonia Refrigeration System 2020. Potential sources of leakages at ice production areas will be identified. It is also expected that presence of ammonia around the ice production area will be detectable since majority of the ice factories have poor maintenance. The concentration of airborne ammonia is expected to be high when the ventilation system in an area is inadequate. It is also expected those factories with poor grading from the audits using ammonia checklist i.e. D and E will likely to have many potential sources of leakages. Furthermore, the research will also be seeking chemical management compliance status among thirty-eight ice factories in Malaysiain order to enhance workers protection in ammonia refrigeration plants.

2.0 MATERIALS AND METHODS

2.1 Research Aims and Objectives

This research aims to create a profile on airborne gaseous ammonia concentration at the ice production facilities by analyzing the data gathered from the monitoring activity, to make comparison between the monitoring data and the compliance status based on both the USECHH Regulations 2000 and the Guideline on Safe Management of Ammonia Refrigeration 2020 and to finally determine the implementation status of control measures at ice-production facilities. It is expected to contribute an added knowledge to the occupational safety and health practitioners, DOSH officers, academia, the public at large and other developing countries about the enhancement of ammonia management in Malaysia. The proposed methodology covers an overview of chemical legislations for ammonia, data collection, analyses of audited data in 2021 for compliance with the chemical legislations and finally future recommendations and suggestions based on the findings as illustrated in Figure 5.

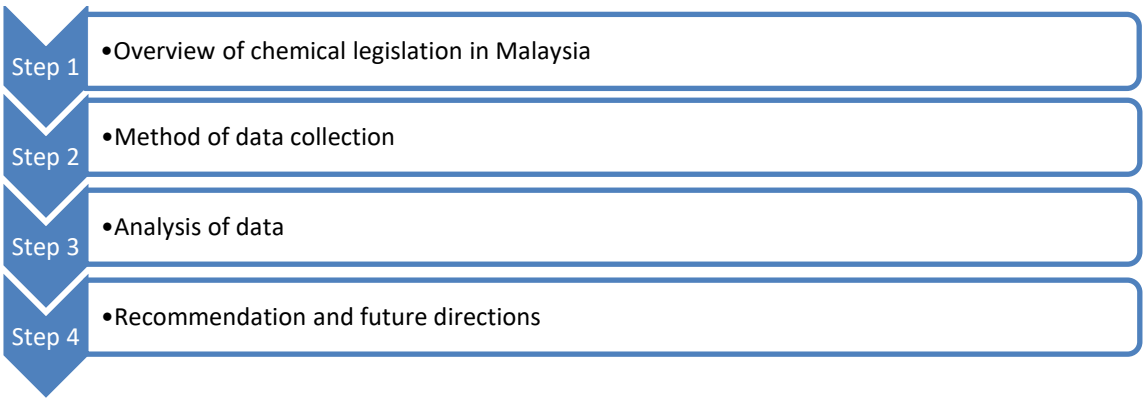

Figure 5: Steps of methodology of the study.

2.2 Step 1: Overview of chemical legislations in Malaysia.

Under this step, an overview of chemical legislations in Malaysia will be investigated. This step aims to probe into occupational safety and health (OSH) law, regulations, guidelines or code of practices related to chemical management particularly ammonia.Most of the data for this step are taken from the OSH enforcement authority's official website. Since this study covers ammonia management,only specific legislation pertaining to ammonia managementat the workplace will be explored.

2.3 Step 2: Method of data collection

This step aims to briefly outline method adopted by the researcher to gather information and to gather data for ammonia profiling. Data gathered are ammonia concentration, air temperature, air humidity, air pressure, air speed and area of the room which includes height from the floor to ceiling of the room. Measurement of ammonia concentration are to be made at six different locations in the respective areas to determine profile of ammonia in ice-production facilities using two different types of direct reading instruments. The focus of measurement is to confirm the presence of ammonia and to determine the source of ammonia or if cross contamination has occurred. Sampling strategy for ammonia profiling developed consist of measurement of certain numbers of sampling points, sampling position and sampling period. The layout of the workplaces selected for sampling are divided into six areas as the following:

i. Machine room
ii. Machine room combined with production room
iii. Tank area
iv. Machine room combined with tank area
v. Production room
vi. Outdoor of the plant.

While parameters to sample are ammonia concentration, air temperature, air humidity, air pressure, air speed and area of the room which includes height from floor to ceiling of the room.

A total of thirty-eight ice production facilities from four different zones in Malaysia were sampled for measurement from the list of one hundred and forty-seven ice production facilities audited in 2021. Data measurement will then be taken simultaneously by the Gasmet GT5000 Terra and a handheld simple ammonia detector as data validator at a static position (at a fixed place). The instruments used are direct reading instruments which will give instantaneous results. Other instruments used in this study are anemometer and measuring tapes or Disto Laser Distance. The data collected will then be analyzed with a statistical software and the gaseous ammonia concentration will be mapped according to the factory layout. Flow chart of the steps is illustrated in Figure 6.

2.4 Step 3: Analyses of Data

Step 3 aims to explore further results of audited and measurement data compiled by the researcher. Each elementsor each provisions of the USECHH Regulations and the Guideline On Safe Management of Ammonia Refrigeration System 2020 with the highest compliance and the least compliance will be analysed. The gap between these two will be analysed. Data was analysed using statistical software and tabulated for analysis.

2.5 Step 4: Recommendations and Future Directions

Step 4 is the most important section of this study since it will critically discuss the findings from Step 1 to Step 3 and propose future recommendations to enhanceammonia compliance of the ice-production facilities. Any limitation or challenges faced during the study will be explored in this step.

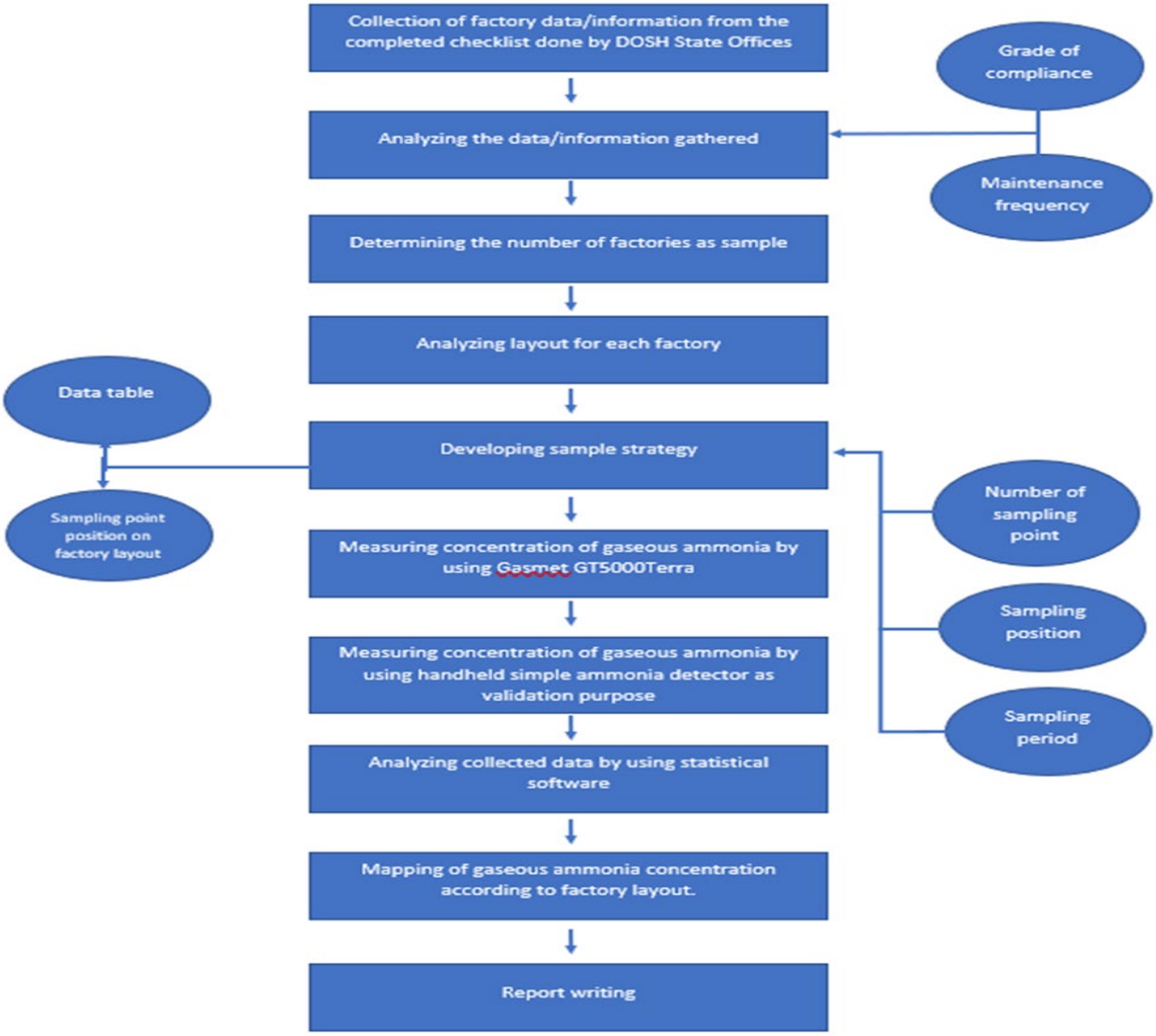

Figure 6: Flow chart of the steps in research methodology

3.0 RESULTS

3.1 Overview of chemical legislations in Malaysia

There are various agencies involved in chemical management in Malaysia. Under the Occupational Safety and Health Act (OSHA) 1994, legislations related to ammonia management fall under the following:

i. Occupational Safety and Health (Control of Industrial Major Accident Hazards) (CIMAH) Regulations 1996
ii. Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) (USECHH) Regulations 2000
iii. Occupational Safety and Health (Classification, Labelling and Safety Data Sheet of Hazardous Chemicals) (CLASS) Regulations 2013
iv. Industry Code of Practice (ICOP) on Chemicals Classification and Hazard Communication 2014

Chemical related guidelines pertaining to ammonia management which have been published by DOSH to assist industries in complying with these regulations are:

i. Guideline On Safe Management of Ammonia Refrigeration System 2020
ii. Guideline on Storage of Hazardous Chemicals 2005
iii. Guidelines of the Control of Chemicals Hazardous to Health 2001
iv. Guidelines on the Use of Personal Protective Equipment Against Chemical Hazards 2005

The USECHH Regulations was gazetted in 2000 to provide a legal framework to control exposure of chemical hazardous to health at the workplace, to set workplace exposure standard in order to protect the health of the employees and others at the place of work and to promote excellence in management chemicals hazardous to health at all workplaces in Malaysia. The regulations applies only to workplaces where chemicals hazardous to health are being used at the place of work. Ammonia is defined as chemicals hazardous to health and therefore need to comply with the provisions of the USECHH Regulations 2000.

On the other hand, the Guideline On Safe Management of Ammonia Refrigeration System 2020 describes how to manage ammonia refrigeration system at the workplace. It also describes duties and responsibilities of employers, designers, manufacturer of vessels and supplier of ammonia on how to maintain and operate the ammonia refrigeration system safely. Legislations governing the use of ammonia at workplace besides the chemical related legislations are, the provisions pertaining to the safe system of plant and work under the Occupational Safety and Health Act 1994, and the provisions pertaining to unfired pressure vessels under the Factories and Machinery Act, 1967. The vessel's provisions are mandatory since ammonia can appear in both forms as gas and liquid. The liquid needs to be stored in an unfired pressure vessel meeting certain standards as required under both acts (Department of Occupational Safety and Health, 2021).

3.2 Analyses Results of Ammonia Measurement

Measurements of ammonia shows the concentration of ammonia varies at the sampled workplaces. The results from the FTIR shows 62 ppm as the maximum reading and 0 ppm as the minimum reading whereas the maximum average reading was 23 ppm. The permissible exposure limit (PEL) of ammonia is 25 ppm and at a concentration of 300 ppm, ammonia is immediately dangerous to life and health. Only one workplace is having ammonia concentration exceeding the PEL whereas five other workplaces are found to be having ammonia concentration in the range of five to twenty-four ppm. According to various literatures, the value which exceed 5 (five) ppm implies that the presence of ammonia in the air can be detected through sense of smell by human.

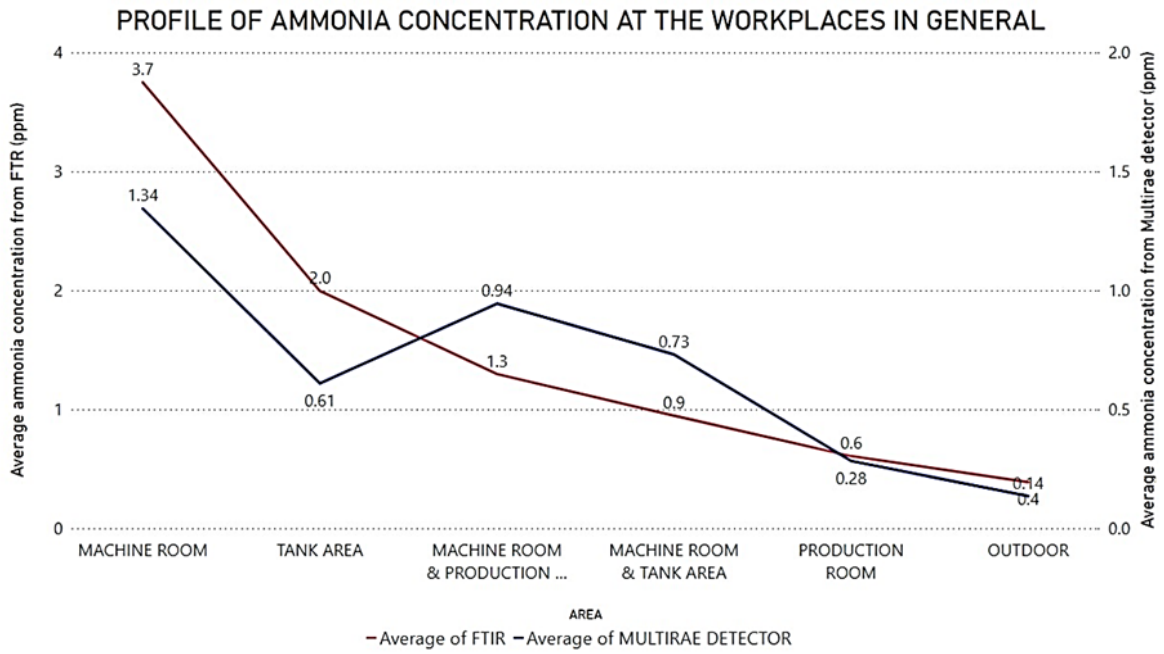

Figure 7: Profile of ammonia concentration using both instruments for six areas.

Figure 7 shows the profile of ammonia according to the six areas identified. Data from Figure 7 has evidently shown that the machine room area with average ammonia concentration of 1.92 ppm was the most exposed area to the airborne ammonia at the ice-production factories. It was then followed by machine room with production room at 1.30 ppm in average, tank area at 0.96 ppm in average, combination of machine room and tank area with 0.95 ppm in average, production room with 0.61 ppm in average and lastly, the outdoor for benchmarking with 0.39 ppm in average. In addition, the measured concentration by both instruments have shown similar trend. This verified that the profiles of airborne ammonia concentration at the ice-production factories were consistent and precise based on their clustered areas.

3.3 Analyses of Chemical Management Compliance Using the Ammonia Guidelines

Audits conducted by DOSH for one hundred and forty seven workplaces having refrigeration facilities in 2021 show that only 95% are ice-production facilities while 5% are food processing industries (Department of Occupational Safety and Health, 2021a). Figure 8 shows the compliance degree with the elements listed in the Guideline on Safe Management of Ammonia Refigeration 2020 of these ice-production facilities. It can be concluded that those facilities in the satisfactory grades ranging from A to C are 34% while those facilities in the unsatisfactory grades (i.e. D and E) are 66%. A total of 97 workplaces need to improve their management of ammonia at the workplaces while 50 workplaces need to maintain their existing systems and procedures or to improve further to better grades especially for those in category C.

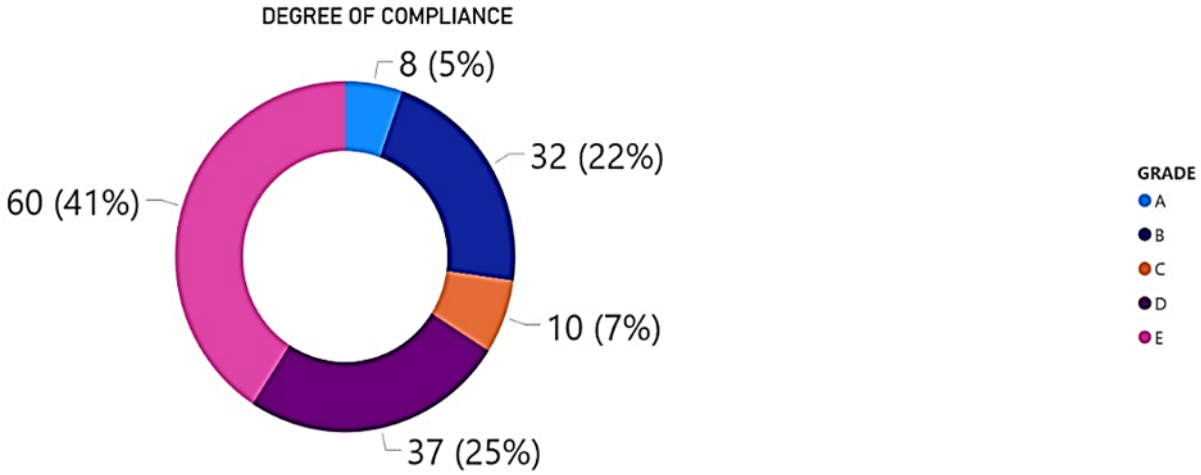

Figure 8: Overall degree of compliance of employers, suppliers of ammonia and suppliers of refrigeration systems.

3.4 Analyses of Chemical Management Compliance and Ammonia Measurement Data

Comparison were made between the ammonia measurement data, the compliance degree of Guideline on Safe Management of Ammonia Refrigeration 2020 for pre-audit (grade before) and the post-audit (grade after) with the the USECHH grade. The existence of ammonia detector at a particular ice-production facility is also observed to see any trend or pattern as compared to the grades. All these audits and assessment using different checklists, were conducted during the ammonia monitoring activity.

Table 1 demonstrates that there is no strong correlation between the monitoring data and the compliance degree of the ammonia Guideline, and the USECHH Regulation 2000 at a particular ice-production facility. The results were found randomly with indistinct pattern, and thus, no conclusion can be made from them. Table 1 also demonstrates that the grading obtained before the audit and after the audits differred.

Table 1: Summary of gradings observed during audits.

Company	USECHH Grade	Ammonia Grade Pre Audit	Ammonia Grade Post Audit	Average ammonia Concentration (ppm)
1	B	E	C	1.19
2	B	E	E	1.88
3	B	A	C	1.93
4	B	D	C	2.94
5	B	C	B	0.30
6	B	B	C	0.56
7	C	D	D	0.54
8	C	B	B	0.65
9	B	A	E	0.27
10	B	B	B	0.55
11	E	C	B	0.27
12	A	E	E	0.15
13	A	E	E	0.15
14	A	D	E	0.00

The gradings from Table 1 shows that despite the enforcement by the authority, the ice-production facilities do not seem to improve. These workplaces are recommended to be audited yearly or at frequent intervals since lack of maintenance of the refigeration system plays a part in introducing high airborne concentration of ammonia in the factory. There could be leakages from the system which will give rise to the presence of ammonia inside the facilities.

4.0 DISCUSSIONS AND RECOMMENDATIONS

The findings of this study from Figure 7 shows that the likelihood of ammonia leakages is still high in ice-production facilities. It was found the compressor in the machine room with the highest ammonia concentration was shutdown halfway during the monitoring activities. This caused a surge in ammonia concentration during the measurement conducted. Various literature reviews concluded that for ammonia refrigeration system, a storage vessel or receiver is the place where the worst-case release quantity is expected to reside (Science Applications International Corporation Reston, VA, 1996). Since ammonia is used in liquid phase and gas phase in the refrigeration system, the system must be equipped with leak prevention system to minimize risks to occupational safety and health and the environment. One of the efforts that can be made to reduce risk to the environment is to keep cooling installation away from the community. During the assessment and monitoring activities in 2022, majority of the ice-production facilities are in the industrial area. Hence, any leakages from the refrigeration system will potentially lead to an emergency that need evacuation before it affects the workers and the community in the area. Many literatures and review of accidents also concludes that maintenance is a principal importance in preventing ammonia releases from refrigeration plants. A sound and well-run inspection, test and preventive maintenance program is essential to preventing equipment failure that could result in a hazardous release of ammonia in these plants.

Most of the contributing factors to ammonia release incidents are due to equipment failures and lack of preventive maintenance programmes and procedures. The results from Figure 7 confirms that ammonia concentration lingers around the machine room or the combination of machine room and the production room. It was found that most workers stationed in the production room to assist in the ice-production activities. Hence, it is essential for both rooms to be well-ventilated to prevent accumulation of ammonia if leaks occur. The results obtained for the USECHH compliance and the ammonia guideline compliance as summarised in Table 1 were not positively correlated. There was a gap found for grading obtained during pre-audit and post-audit using the ammonia guideline checklist. These results can be used to make inference that existing maintenance system in ice-production facilities, and the OSH compliance standard is poor among the refrigeration plants. Hence, it can be safely concluded that new strategies need to be taken on the sampled workplaces to improve their chemical safety management and to prevent ammonia release incidents.

The ammonia profiles obtained from this research can be used as a basis for further risk modelling for ammonia leakage involving ice-production facilities. It is recommended to investigate worst possible scenario for ammonia leakages and identify safe distance from the workplaces in case of leakages. In Malaysia, research or consequences modelling is scarce and it is worth venturing into future research on this consequences modelling. Adequate control measures can be taken to reduce the vulnerability against such incidents. Data validation for ammonia profile using both instruments confirmed the results and many possible improvements could be made to the layout of the ice-production facilities. Figure 7 confirmed that many ice-production facilities are having combination rooms to save space. Workers are easily affected and exposed to ammonia due to this constraint. Many ice-production facilities are in industrial areas and close to community. Hence, comprehensive emergency response plan for ammonia refrigeration is required to mitigate consequences during any emergency.

Based on the results of research, the following actions are recommended:

i. The compliance gap between the USECHH Regulations and the ammonia guidelines need to be identified and enhanced.
ii. Grading for post and pre-audit gap to be minimised and identified.
iii. Yearly audits to all these ice-production facilities is recommended.
iv. Ammonia leak detector to be installed as one of the immediate measures for all ice-production facilities as a first line of defence.

v. To redesign ice plant or factory layout by proper segregation with adequate ventilation and proper maintenance of the machinery in the ice-production facilities based on the profile of ammonia concentration obtained from this research.
vi. Comprehensive emergency planning is required for all refrigeration plants using ammonia.

5.0 CONCLUSION

The objective to study profiling of ammonia concentration at ice-production facilities and to investigate compliance level using USECHH Regulations 2000 as a parameter to determine compliance through this research has been achieved. The ammonia profile obtained from this study is found to be valid and consistent upon validation and verification by the research team. The USECHH compliance data is found not to be positively correlated to the ammonia checklist compliance for pre-audit and post-audit. The level of ammonia concentration obtained also does not correlate to the results of pre-audit or post-audit conducted. Recommendations suggested should be planned to ensure its successful implementation and good management of ammonia at refrigeration plants throughout the country in order to enhance workers' protection.

References

[1] Bhattercharjee G., S. Bhattacharya, R.K. Gangopadhyay & S.K. Das. (2012). Accidental Emission of Ammonia from Cold Storage and Ice Factory in Kolkata and its Remedial Action. *International Journal of Industrial Engineering and Management Science,*, 1-4.
[2] Chen, S.N., Sun, J.H., Chu, G.Q. (2007). Small scale experiments on boiling liquid expanding vapor explosions. *Jouranl of Loss Prevention in the Process Industries 20*, 45-51.
[3] Department of Occupational Safety and Health. (2021, January 27). *Occupational Safety and Health Act*. Retrieved from DOSH: https://www.dosh.gov.my/index.php/legislation/acts-legislation
[4] Department of Occupational Safety and Health (2021a). *Post Mortemof Ammonia Refrigeration Audits.* Putrajaya: DOSH
[5] Department of Occupational Safety and Health (DOSH). (2022, February 6). *Legislation- Guidelines.* Retrieved from Official Website Department of Occupational Safety and Health: https://www.dosh.gov.my/index.php/legislation/guidelines/chemical/3873-guidelines-on-safe-management-of-ammonia-refrigeration-system/file
[6] DOSH. (2020). *Summary Report Hazardous Chemical Inventory.* Kuala Lumpur: DOSH.
[7] MHI, Melaka Hari Ini. (2020, November 10). 'Terhidu gas ammonia amat menakutkan'. Melaka, Tanjung Bidara, Malaysia.
[8] Science Applications International Corporation Reston, VA. (1996). *Model Risk Management Program and Plan For Ammonia Refrigeration: RMP for Ammonia Refrigeration Facilities.* New Jersey: EPA.
[9] Zhao, L.J, et. al. (2018). An Analysis of Hazardous Chemical Accidents in China between 2006 and 2017. *Sustainability*, 2935.