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Safety Analysis of Ammonia Exposure at a Chemical Plant

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ABSTRACT

The Environmental Protection Agency (EPA) is issuing this Alert as part of its ongoing effort to protect human health and the environment by preventing chemical accidents. In chemical manufacturing industry, there are many hazards in the workplace particularly chemical hazard. Although there is safe work procedure for activities involving chemical handling, however, incidents of ammonia exposure are still occuring. Therefore, assessment on the workplace conditions and the knowledge and attitude of employees is essential to evaluate the extent of the problem. Accordingly, the objectives of this study are to (1) identify potential exposures, possible effects and root causes of ammonia exposure to workers, (2) to analyse knowledge and attitude of workers on ammonia exposure, and (3) to propose recommendations (guideline) for the improvement of safety handling of ammonia. A Job Safety Analysis was conducted to identify potential exposures, possible effects and root causes of ammonia exposure to workers. Knowledge and attitude questionnaire was conducted for 36 production workers of a company to analyse their knowledge and attitude on ammonia exposure. The results show that the potential ammonia exposures were from this areas; improper carboy cap fastening and lid absence, transfer spillage, residuals splashes, overcharging and continuous pumping, hose leakage, loose and dismantled, rushed scooping, manhole exposure, and charge-in pump not halted. The possible effects of ammonia exposures are carboy leaked, overspill, hose leaked, forced out through loosened hose, ammonia evaporated to fumes, ammonia fumes inhaled into respiratory system, sprinkles and splashes, and direct contact with skin and eyes. The root causes of ammonia exposures are; no initial checking, not wearing PPE, improper pouring method, mixing tank unattended, procedure overlooked, rushing, not following proper procedure, and pump control unattended. The workers' knowledge of ammonia exposure was high, whereas their attitude was moderate. A guideline was proposed to improve safety handling of ammonia and enhance the knowledge and attitude of workers.

Keywords:
Ammonia, Chemical, Exposure, Knowledge, Attitude

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1. Introduction

Ammonia is a mixture of the elements of nitrogen and hydrogen which make up the formula of this compound which is NH_3. It is colourless, volatile, corrosive in nature, and also emits a pungent smell [1,2,3]. It can cause a skin and eye irritation rapidly to a directly exposed person. A concentrated ammonia can cause major burns that result in permanent scars and blindness. Exposure via inhalation can cause severe coughing, nose and throat irritation. Many occupational exposures have been found to be linked with sinusitis which is sinus infection, irritation in the eye and upper airway. High levels of ammonia being exposed to a person drastically will have diseases in the lower airways and interstitial lung [4,5]. Ammonia can be very toxic and fatal if one inhales it unknowingly. The respiratory tract of a person may corrode as a result from inhaling it. Household cleaners that contain ammonia can cause unexpected accidents such as indirect accidental swallowing [6,7,8].

At a chemical manufacturing plant, most of the activities in manufacturing and production process involves mainly in the use of chemicals. Among all of the chemicals, ammonia is the most widely used chemical, of which is used as a raw material in producing other specialized chemicals. Although that there are safety guideline and procedure regarding the activities or tasks involving the handling of chemicals generally and ammonia specifically, but the issues regarding the exposure of ammonia are still prevalent. According to the accident reports, there are several reported incidents that occurred from the year 2012 to 2017 involving production workers being exposed to ammonia [9,10,11]. In all of the reported incidents of ammonia exposure, most of the causes were due to the unsafe conditions such as spillage and hose leakage, and also unsafe acts or behaviours such as mishandling, skipping procedure, not wearing or improperly wear Personal Protective Equipment (PPE)[12].

In order to identify the type of conditions that is unsafe to the workers, it is important to conduct a safety analysis on how job tasks are being carried out in order to diagnose the problems and how it can lead to the exposure of ammonia. The consequences or effects of the problems need to be determined so that a preventive or control measures can be proposed. The level of compliant by the employees to the safety rule is related with the aspect of behaviour. In order to further understand the level of compliant of the workers to the rule and regulation, there is a need to assess the two important elements that influence how a person behave, which are the element of knowledge, and attitude. Therefore, a safety analysis on the working procedures as well as the assessment on the level of knowledge and attitude of the employees working in the production area is essential in order to evaluate the extent of the problem. The results of the assessments are important in order to rectify the issue, by proposing an appropriate safety intervention that suited the circumstances regarding the exposure of ammonia at the chemical manufacturing plant.

2. Methodology

This research project utilized a qualitative method of Job Safety Analysis (JSA) in order to identify the potential exposures, possible effects and root causes of ammonia exposure to the production workers. The JSA survey was conducted through a visit to the manufacturing plant and with further assistance and discussions with the representatives of the company which are the chemical engineer, HSE executive and production workers.

This research project also adapted [13,14,15] and applied a quantitative method of Knowledge and Attitude Questionnaire which was given to a population of 36 employees who work at the production area of ABC Electronics Solutions (M) Sdn. Bhd. manufacturing plant, Kuching. This questionnaire was used in order to analyse the knowledge and attitude of the workers regarding

ammonia exposure. After they have answered the questionnaire, their responses in the answered questionnaire are coded and inputted into the statistical analysis software of IBM Statistical Package for the Social Sciences (SPSS).

3. Results and Discussion

3.1 Job Safety Analysis

3.1.1 Potential exposure

Table 1 shows the potential exposure to each job task in the line of production of the manufacturing company of which according to the HSE executive, chemical engineer and production workers, have happened before and could potentially occurred again in the future or in the manufacturing company. In the first job task which is during storing, it is discussed that the potential exposure of ammonia towards production workers is that the carboy cap was not properly fastened and there was an absence of lids covering the carboys. In the next job task, namely staging, the potential exposure of ammonia towards the production workers that occurs is that ammonia can potentially spill during transfer to reservoir tank. The third job task after staging is rinsing of mixing tank and the potential exposure of ammonia towards the production workers that could happen is the splashing of ammonia residuals during rinsing of mixing tank. The fourth job task is charging and adjustment and there are several potential exposures of ammonia towards the production workers at this stage. Firstly, overcharging and continuous pumping of the mixing tank could cause potential exposure of ammonia to the production workers working nearby it. Secondly, the leakage of hose can potentially expose the ammonia to the production workers. Lastly, a potential exposure of ammonia is that the hose is loose and dismantled during the charging and adjustment. The last job task is the sampling of ammonia that could potentially cause exposures of ammonia towards production workers. Firstly, rushed scooping of ammonia sample could cause ammonia to spill. Secondly, ammonia can be directly exposed through the manhole of the mixing tank. Lastly, a potential exposure can be caused when charge-in pump is not halted during sampling of ammonia.

Table 1
Potential exposures of each job task

No.	Job Task	Potential Exposure	
1	Storing	i.	Carboy cap not properly fastened and absence of lid.
2	Staging	i.	Ammonia spilling during transfer to reservoir tank.
3	Rinsing	i.	Splashes of ammonia residuals.
4	Charging and Adjustment	i.	Overcharging and continuous pumping.
		ii.	Hose leakage.
		iii.	Hose is loose and dismantled in the process.
5	Sampling	i.	Rushed scooping causing ammonia spill.
		ii.	Exposure of ammonia through manhole.
		iii.	Charge-in pump was not halted during sampling.

3.1.2 Possible effect

Table 2 shows the possible effects to each job task in the line of production of the manufacturing company of which according to the HSE executive, chemical engineer and production workers, have happened before and could potentially occur again in the future or in the manufacturing company. During storing, one of the effects that could affect the production workers is the leakage of HDPE carboy which in turn causes ammonia to be evaporated into fumes. Due to this, ammonia fumes are inhaled into workers' respiratory system. During the second job task which is staging, the effect that ammonia exposure could cause towards the production workers is that it could come into direct contact with the skin of production workers handling the carboys when there is an ammonia spill during transfer to reservoir tank. In the third job task which is rinsing, one effect of ammonia exposure is that the ammonia could also come into direct contact with the skin of production workers who are rinsing the mixing tank. During the fourth job task, during charging and adjustment, there are a few effects that ammonia exposure could cause to production workers. Firstly, ammonia could overspill out of the mixing tank during overcharging of mixing tank. Due to this, it can come into direct contact with operators who are working closely to the mixing tank. Secondly, ammonia may leak through the hose of the mixing tank and may come into contact with the operators working closely to it. Next, ammonia could potentially be forced out of the loosened hose of the mixing tank. This, in turn, will cause a direct contact exposure of the production workers towards ammonia. During the last stage which is sampling, the effects during rushed scooping of sampling of ammonia is that the ammonia scooped could sprinkle to operator causing a direct skin contact of ammonia with them. Secondly, ammonia is inhaled by operator through the manhole. Other than that, ammonia could come into direct contact with skin of operator during scooping. Lastly, if the charge-in pump is not halted during sampling, ammonia could sprinkle to the operators and cause a direct skin contact exposure.

Table 2
Possible effects of each job task

No.	Job Task	Possible Effects	
1	Storing	i.	Leakage of HDPE carboy causing the ammonia to evaporate into fumes.
		ii.	Ammonia fumes are inhaled into the workers' respiratory system.
2	Staging	i.	Direct contact with skin.
3	Rinsing	i.	Direct contact with skin.
4	Charging and Adjustment	i.	Ammonia overspill out of mixer.
		ii.	Ammonia comes in contact with operators.
		iii.	Ammonia leaked through the hose and may come in contact with operators.
		iv.	Ammonia forced out through the loosened hose
		v.	Ammonia comes in contact with operators.
5	Sampling	i.	Ammonia sprinkles to operator causing direct skin contact.
		ii.	Ammonia is inhaled by operator.
		iii.	Direct contact with skin of operator.
		iv.	Ammonia sprinkles to operator causing direct skin contact.

3.1.3 Root cause

Table 3 shows the root causes of each potential ammonia exposure in the line of production of the manufacturing company of which according to the HSE executive, chemical engineer and production workers, have happened before and could potentially occur again in the future or in the manufacturing company. The first job task of storing has the root causes of the overlooking of suppliers towards the details of the carboy sent to the manufacturing company. Next, operators who receive the items from the suppliers did not check the details which could cause a potential exposure to ammonia. The second job task of staging has the root causes of not wearing proper personal protective equipment (PPE) in conducting the task such as hand gloves or face shield and also the improper way of pouring ammonia from carboy to the reservoir tank. The third job task of rinsing of mixing tank, a root cause that could potentially expose ammonia to the production workers is by not wearing the proper personal protective equipment (PPE) such as hand gloves or face shield. At fourth job task of charging and adjustment, the root causes are the overcharging and continuous pumping is caused by the mixing tank not being attended by the designated operators who are supposed to operate it. Other than that, the leaking of ammonia through the hose is caused by not checking the hose that connects the pump and the mixer inlet before conducting the charging process. Lastly, loosened hose is caused by operator overlooking the procedure and forgot to secure the hose fastener. During sampling of ammonia, the root cause of potential exposure of ammonia during rushed scooping is because of not using proper personal protective equipment (PPE). Operators tend to rush during scooping and not following the correct procedure of using the dipper. Ammonia could be exposed through manhole because the operator does not use respirator when scooping out the ammonia. They also do not use proper face shield or hand gloves which can cause an exposure towards ammonia. Lastly, charge-in pump not halted during sampling is because the pump control is overlooked or not attended by operator designated at the mixing tank.

Table 3
Root causes of each job task

No.	Job Task	Root Causes	
1	Storing	i.	Overlooked by suppliers.
		ii.	Not checked by operators that receive from the suppliers.
2	Staging	i.	Not wearing PPE.
		ii.	Improper way of pouring ammonia from carboy.
3	Rinsing	i.	Not wearing PPE.
4	Charging and Adjustment	i.	Mixing tank is not attended by the operator.
		ii.	Hose that connects the pump and the mixer inlet is not checked before conducting the charging process.
		iii.	Operator overlooked the procedure and forgot to secure the hose fastener.
5	Sampling	i.	Not using PPE.
		ii.	Rushing and not following proper procedure.
		iii.	Not wearing respirator.
		iv.	Not wearing face shield and hand gloves.
		v.	Pump control overlooked or not attended by operator.

3.2 Knowledge and Attitude Questionnaire

3.2.1 Sociodemographic Profile

The information regarding the sociodemographic profile that were enquired through the questionnaire are their age, their level of education, the duration or years of experience of working in the company, and experience of ammonia accident. The sociodemographic data of the respondents are demonstrated in the following Table 4.

Table 4
Descriptive characteristic of the respondents

Parameter	Sociodemographic Characteristics	Number (%)
Age range	19 years old and below	4 (11.1)
	20 to 29 years old	16 (44.4)
	30 to 39 years old	11 (30.6)
	40 to 49 years old	3 (8.3)
	50 years old and above	2 (5.6)
Education level	Primary school	2 (5.6)
	Secondary school	16 (44.4)
	Certification	14 (38.9)
	Higher institution	3 (8.3)
	No formal education	1 (2.8)
Years of service	Less than 1 year	4 (11.1)
	1 to 2 years	12 (33.3)
	3 to 4 years	9 (25.0)
	5 to 6 years	7 (19.4)
	More than 6 years	4 (11.1)
Accident experience	Yes	9 (25)
	No	27 (75)

For the ranges of age, the first range which is the age of 19 years old and below has a number of respondents of 5 persons. The second range which is the age of 20 years old to 29 years old has a number of respondents of 18 persons. The third group which is the age of 30 years old to 39 years old has a number of respondents of 11 persons. The fourth group which is the age of 40 years old to 49 years old has a number of respondents of 1 person. The last group which is the age of 50 years old and above has a number of respondents of 1 person. Out of the 36 participants involved in this

research project, majority of the respondents are within the age group of 20 years old to 29 years old which is the age group that has the highest number with a percentage of 50%. On the other hand, the age groups that share the lowest number are the age group of 40 years old to 49 years old and 50 years old and above with a percentage of only 2.78% respectively. The data of the respondents collected for the ranges of age are displayed in the following Figure 1.

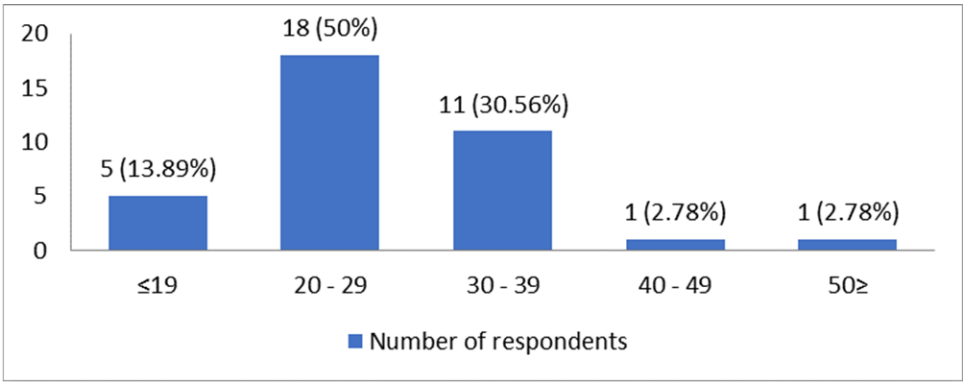

Fig. 1. Number and percentage of respondents for the age ranges

For the level of education, the level of education was categorized into 5 different tiers, which are primary school, secondary school, certification, higher institution and no formal education. The first level which is the 'primary school' has a number of respondents of 7 persons. The second group which is the 'secondary school' has a number of respondents of 15 persons. The third group which is the 'certification' has a number of respondents of 11 persons. The fourth group which is the 'higher institution' has a number of respondents of 2 persons. The last group which is the 'no formal education' has a number of respondents of 1 person. Majority of the respondents have secondary school education which is the education level that has the highest number with a percentage of 41.67%. On the other hand, the level of education that has the lowest number is having no formal education which has a percentage of only 2.78%. The data of the respondents collected for the level of education are shown in the following Figure 2.

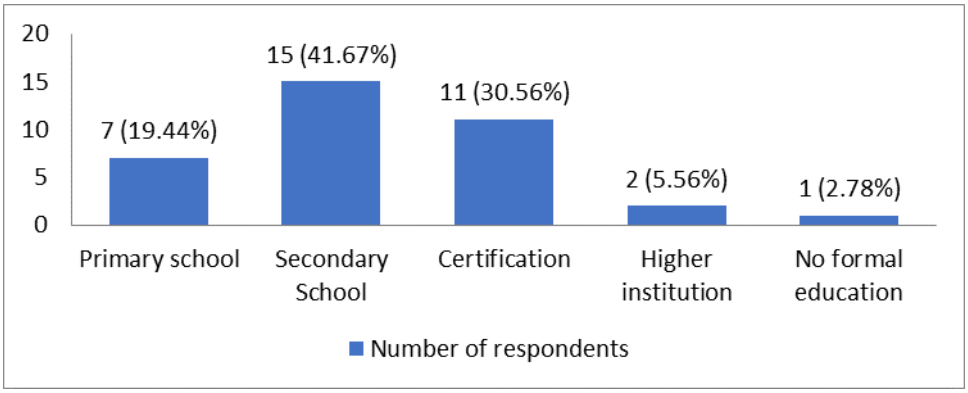

Fig. 2. Number and percentage of respondents for the education level

For the years of service, the respondents' years of experience working in the company is divided into 5 ranges of years, which are less than 1 year, between 1 to 2 years, between 3 to 4 years, between 5 to 6 years and more than 6 years. The first range which is the 'less than 1 year' has a number of respondents of 9 persons. The second range which is the 'between 1 to 2 years' has a number of respondents of 14 persons. The third range which is the 'between 3 to 4 years' has a

number of respondents of 7 persons. The fourth range which is the 'between 5 to 6 years' has a number of respondents of 3 persons. The fifth range which is the 'more than 10 years' has a number of respondents of 3 persons. Majority of the respondents with a percentage of 38.89% have experience of working in the company at the range of between 1 to 2 years which has the highest number with a number of respondents of 14 persons. On the other hand, the range of years that share the lowest number is the range between 5 to 6 years and above 6 years of experience working in the company with a number of respondents of 3 persons respectively have a percentage of 8.33%. The data of the respondents collected for the years of experience working in the company are displayed in the following Figure 3.

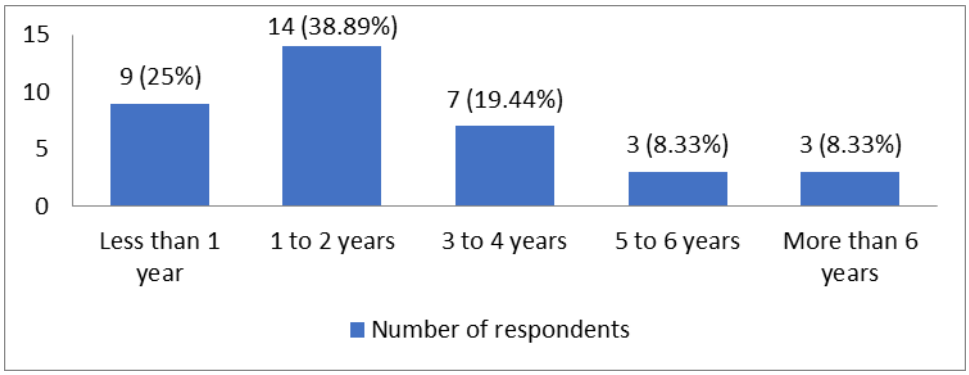

Fig. 3. Number and percentage of respondents for the years of service

Other than that, the respondents were also asked in the questionnaire whether they had any experience of accident or near miss incident at their workplace that are related with ammonia for the last 12 months. Majority of the respondents with a percentage of 75% had chosen 'No' as their answer with a number of respondents of 27 persons. On the other hand, respondents that actually had experienced at least an accident or near miss incident that are related with the exposure of ammonia at their workplace for the last 12 months are only 9 persons with a percentage of 25%, which had chosen 'Yes' for their answer to this question. The data of the respondents collected in term of having any experience in accident or near miss incident at their workplace for the last 12 months are displayed in the following Figure 4.

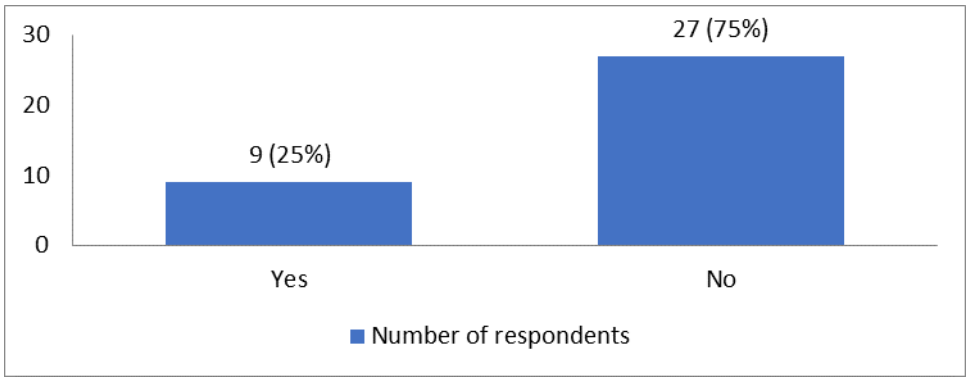

Fig. 4. Number and percentage of respondents for the accident experience

3.2.2 Knowledge and attitude

The findings on the level of knowledge and attitude were further analyzed with respect to the sociodemographic profile of the respondents, which are the age, education level, years of service, and accident experience. For all the following level of scores obtained, it was based on the modified assessment level of scoring categorization adapted from Mahlangu and Kruger [16]) as tabulated in Table 5.

Table 5
Assessment level of scoring categorization adapted from Mahlangu and Kruger [16]

Assessment Level	Score
Very High	4.5 – 5.0
High	4.0 – 4.4
Moderate	3.0 – 3.9
Very Low	1.0 – 2.9

The mean value for the whole question of the questionnaire survey, namely the level of knowledge of the production workers on ammonia exposure at the manufacturing company is 4.18. Hence, the level of knowledge regarding ammonia exposure among the production workers is at a high level. The mean value for the whole question of the questionnaire survey, namely the level of attitude of the production workers on ammonia exposure at the manufacturing company is 3.81. Hence, the level of attitude regarding ammonia exposure among the production workers is at a moderate level (Table 6).

Table 6
Total mean score of knowledge and attitude score

	Knowledge	Attitude
Total Mean Score	4.18	3.81
Assessment Level	High	Moderate

The level of knowledge and attitude of the respondents regarding the ammonia exposure at their workplace have been evaluated according to the five different age ranges in Table 7. Overall, all of the age ranges of respondents had obtained a high level of scores for knowledge and a moderate level of attitude. It is observed that the difference of means between the score points received from both two aspects of knowledge and attitude have a p-value of 0.770 and 0.948 of which are higher than 0.05. Hence, the difference of means for both of the knowledge and attitude aspect were statistically insignificant with the age ranges ($p>0.05$).

Table 7
Mean of knowledge and attitude score based on age ranges

Aspect	≤19 (n=5)	20-29 (n=18)	30-39 (n=11)	40-49 (n=1)	≥50 (n=1)	p-value
Knowledge	4.22	4.16	4.21	4.22	4.11	*0.770*
Attitude	3.89	3.77	3.89	3.89	3.44	*0.948*

The findings for the level of knowledge and attitude of the respondents regarding the ammonia exposure at their workplace with respect to the education level variable have been evaluated and categorized in five different levels of education in Table 8. In general, for the knowledge aspect, all of the level of education of respondents had obtained a high level of scores, whereas for the aspect of attitude, all of the level of education is at moderate level. The means for both of the knowledge and attitude are also statistically insignificant as both of the p-values of 0.705 and 0.511 are larger than 0.05. From the table, it can be observed that workers that have an education level of higher institution acquired the highest score in the aspect of knowledge (4.28) which is at high level. On the other hand, workers with the education level of primary school acquired the lowest score in the aspect of attitude (3.50), which is at the level of moderate.

Table 8
Mean of knowledge and attitude score based on education level

Aspect	No formal education (n=1)	Primary school (n=7)	Secondary school (n=15)	Certification (n=11)	Higher Institution (n=2)	p-value
Knowledge	4.22	4.16	4.16	4.21	4.28	0.705
Attitude	3.89	3.50	3.99	3.78	3.83	*0.511*

For the variable of the years of service, the mean of knowledge and attitude scores regarding the ammonia exposure at their workplace are presented in Table 9. As observed in Table 9, the level of knowledge is at high level for all the years of service. The highest level of attitude is observed at the years of service of more than 6 years with a mean value of 4.22. For the attitude aspect, the lowest level of years of service is the “1 to 2 years” which have the mean value of 3.65. Across the groups for both of the knowledge and attitude, no obvious trend of correlation is observed. As the p-values for both means of knowledge and attitude are observed to be higher than 0.05, hence, statistically there was no significant difference between the mean of the knowledge and attitude aspects and the duration of working experiences.

Table 9
Mean of knowledge and attitude score based on education level

Aspect	<1 (n=9)	1-2 (n=14)	3-4 (n=7)	5-6 (n=3)	>6 (n=3)	p-value
Knowledge	4.16	4.19	4.21	4.15	4.22	*0.918*
Attitude	3.88	3.65	4.02	4.04	3.70	*0.662*

The level of knowledge and attitude of the respondents regarding the ammonia exposure at their workplace have been evaluated according to the variable of accident experience as presented in Table 10. The respondents were asked whether they have ever experience any type of incident or near-miss involving the exposure of ammonia for the past 12 months of their employment at the company. Based on Table 4.10, it can be observed that both of the level of knowledge for respondents that had experienced accident and never experienced accident are at high level, which are 4.23 and 4.19 respectively. As the p-value for the knowledge aspect of 0.193 is higher than 0.05, hence there is no significant difference between the means of "Yes" and "No" of the accident experience. For the aspect of attitude, respondents that had experienced an accident demonstrated higher score than respondents that had never experienced any kind of accident at the workplace in the past 12 months. The level of attitude for the respondents that had experienced an accident is 4.73, which is very high. Alternatively, the level of attitude of respondents that had never experience any accident involving ammonia exposure is 3.51, which is at the level of moderate. Remarkably, it can be observed that the p-value of the attitude aspect of 0.000 is lower than 0.05, of which implies that there is a significant difference between the means of "Yes" and No" of the accident experience.

Table 10
Mean of knowledge and attitude score based on accident experience

Aspect	Yes (n=9)	No (n=27)	p-value
Knowledge	4.23	4.19	*0.193*
Attitude	4.73	3.51	*0.000*

4. Conclusion

This paper shows a method to analyze hazard in chemical plants and to practice inherent safety measures for decreasing consequences. Hazard analysis method of this work is reconsidered about worst case scenario widely has being used in the world The findings of the research project showed that the potential ammonia exposures to the production workers are improper carboy cap fastening and lid absence, transfer spillage, residuals splashes, overcharging and continuous pumping, hose leakage, loose and dismantled, rushed scooping, manhole exposure, and charge-in pump not halted. The possible effects of ammonia exposures to the production workers are carboy leaked, overspill, hose leaked, forced out through loosened hose, ammonia evaporated to fumes, ammonia fumes inhaled into respiratory system, sprinkles and splashes, and direct contact with skin and eyes. The root causes of ammonia exposures to the production workers are no initial checking, not wearing PPE, improper pouring method, mixing tank unattended, procedure overlooked, rushing, not following proper procedure, and pump control unattended. The level of knowledge of the production workers regarding ammonia exposure in the manufacturing plant is high. The level of attitude of the production workers regarding ammonia exposure in the manufacturing plant is moderate.

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