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Feasibility Study on the Imperatives for the Simulation of Ammonia Release Management

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Abstract
Ammonia is being exported through Bintulu Port via pipeline and loaded to the vessel (ship) using marine loading arm. Ammonia is toxic in nature and transferred at -33 ^{o}C. Marine loading arms are special equipment for loading and unloading liquid cargo from the wharf and the vessel with swivel joints, and supplemented by supporting structure, and other accessories. Loading arms have safety features such as that we can set up quick release mechanism, in which the loading arm will decouple from the manifold when there is an emergency, or the movement of vessel is out of range. Studies such as by United Kingdom (UK) Health and Safety Executive (HSE) on loading arm had provided the probabilities of failures, and the possible size of hole such as guillotine break or 0.1 cross sectional area of pipe. This information, with ammonia operational parameters such as internal and external pressure and ammonia liquid flow rate we can thus predict the amount of ammonia release. Combining with meteorological data information, local landscape conditions and utilizing ALOHA software, we are able to simulate ammonia dispersion and thus predicting the impact of toxicity of ammonia release on the population within the area. This paper is a feasibility study that use modelling approaches to manage ammonia leakage.
Keywords: Ammonia, Loading Arm, ALOHA, Failure Rate

Introduction

Ammonia is one of the bulk liquid dangerous cargoes for export through the ports or terminals. It is loaded to vessel by loading arm, a safe and efficient way of ammonia transfer from wharf to the vessel. Ammonia is a bulk liquid risky cargo that can be shipped through ports or terminals. It is loaded onto the vessel using a loading arm, which is a safe and effective method of transferring ammonia from the wharf to the vessel. The loading arm with automatic quick release in which it can disengaged the ship side and the land side. Loading arm have limited range vertically and horizontally and will also be activated once the range is exceeded.

The loading arm has an automatic rapid release that allows it to disconnect the ship and land sides. The vertical and horizontal range of the loading arm is limited, and it will be activated if the range is exceeded. Because the loading activity is taking place within the port's inner harbour, there is a chance of ammonia leakage or discharge into the atmosphere, which could impact the population. Since the loading operation is within the inner harbour of the port, there is concern about the risk of ammonia leak or release into the atmosphere, potentially affecting the population around the port (Rajeev et al., 2019). There were concerns whether there is a need to provide proper toxic shelter or refuge as a mitigation measures (Tarkington et al., 2009) whenever there is an ammonia accidental release. Because the loading process is taking place within the port's inner harbour, there is a possibility of ammonia leakage or release into the atmosphere, potentially endangering the port's surrounding population. There have been questions over whether sufficient poisonous shelter or refuge should be provided as a mitigating mechanism if ammonia is accidentally released.

Behaviour of Ammonia Upon Release

Ammonia is a colourless, lighter-than-air gas with a strong odour. At -330 °C, it becomes liquid. When ammonia is released into the air, it can behave in three ways: as a superheated liquid, a pressurised liquid under boiling point, or a gas (Che Hassan et al., 2009). When liquid ammonia is discharged into the environment, it transforms and vaporises, generating a moving cloud. The migration is influenced by factors such as wind speed, direction, pasquil stability, temperature, and relative humidity in the environment (Che Hassan et al., 2009). As a result, simulations of migration from the starting condition to the expected ultimate locations are required. The inventory of releases, pipeline temperature, leak source or mechanism, surface type, roughness, internal pressure, ambient pressure, and temperature will all influence this (Abbaslou & Karimi, 2019).

Simulation Software

Various studies and various software had been used for simulation. For this study, ALOHA is use as it is free; thus, it is widely used by experts, organizations, and departments. Lee et al. (2018) indicated that ALOHA is the best simulator for the determination of ammonia toxicity.

Toxic Effect of Ammonia upon Release

When an event involving hazardous chemicals occurs, ALOHA utilises Acute Exposure Levels (AEGL) as toxic Levels of Concern. ALOHA will create threat zones that are denoted by the colours yellow, orange, and red. As a rule of thumb, the modelling assumes a 60-minute exposure length as the default LOC. The three AEGL tiers are defined as follows:

- AEGL-3 is the concentration of a material in the air, defined in parts per million (ppm) or milligrammes per cubic metre (mg/m^3), at which the general population, including vulnerable people, is expected to incur life-threatening health effects or death.
- AEGL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- AEGL-1 The airborne concentration (in ppm or mg/m^3) of a material at which the general public, including susceptible people, is expected to feel noticeable pain, irritation, or certain asymptomatic nonsensory effects. The effects, however, are not crippling and are temporary and reversible if the exposure is terminated.

There are studies about ammonia exposure and effect on human (Table 1A) and (Table 1B).

Table 1A: Signs and Symptoms on Ammonia Exposure to Human

Exposure (ppm)	**Signs and Symptoms**	
References	(Murphy, 2007)	The Fertilizer Institute – Health and Effect of Ammonia
50	Irritation to eyes, nose and throat (2 hours exposure)	Mild discomfort
100	Rapid eye and respiratory tract irritation	Nuisance to eyes and throat irritation
250	Tolerable by most people (30-60 minutes exposure)	
700	Immediately irritating to eye and throat	
700-1700		Incapacitation from tearing of eyes and coughing
>1500	Pulmonary oedema, coughing	
2500-4500	Fatal (30 minutes exposure)	
Less 5000		Usually, recovery without pulmonary complication
5000-10000	Rapid fatal due to highway obstruction, may cause skin damage	Fatalities due to obstruction of airways

Table 1B: Signs and Symptoms on Ammonia Exposure (ANSI/CGA G-2.1-2014)

Concentration/Time	**Effect**
20 ppm to 50 ppm	Mild discomfort, depending on whether an individual is accustomed to smelling ammonia
50 ppm to 80 ppm for 2 hours	Perceptible eye and throat irritation
100 ppm	Nuisance eve and throat irritation
134 ppm for 5 minutes	Tearing of the eyes, eye irritation, nasal irritation, throat irritation, chest irritation
140 ppm for 2 hours	Severe irritation, need to leave the exposure areas
300 ppm to 500 ppm for 30 minutes	Upper respiratory tract irritation; tearing of the eyes (lacrimation), hyperventilation
700 ppm to 1700 ppm	Incapacitation from tearing of eyes
5000 ppm to 10000 ppm	Rapidly fatal
10000 ppm	Promptly fatal

From the above data and based on EPA guidelines for ammonia AEGL (National Research Council, 2008) gives the following data:

Table 2: AEGL For Different Durations

Classification	10 minutes	30 minutes	1 hour
AEGL 1	30 ppm	30 ppm	30 ppm
AEGL 2	220 ppm	220 ppm	160ppm
AEGL 3	2700 ppm	1600 ppm	1100 ppm

As a result, the following figure was used for simulation purposes:

- AEGL 1 is 30 ppm - based on EPA guidelines for ammonia AEGL.
- AEGL 2 is 200 ppm - in the case of evacuating personnel, and from ANSI/CG
- AEGL 3 is 5000 ppm - deadly and instant mortality – for risk assessment

The Loading Arm

The loading arm is a mechanical device that was created to aid in transportation of liquid cargo from the wharf to the ship or vessel. Loading arm can be specified/designed to account for tanker movement during loading and unloading owing to tides, waves, and wind, as well as the tanker's cargo increasing or decreasing. Each loading arm is built to operate within a specific 'envelope.' If a coupled loading arm is pushed beyond of this range, it should be detached right away (manually or, for some systems, automatically). The most important aspects to consider are Tanker DWT, tidal range, maximum wave height, jetty structure elevation, and the size/number of loading arms at the berth are all factors that influence the required operating envelope (Figure 1).

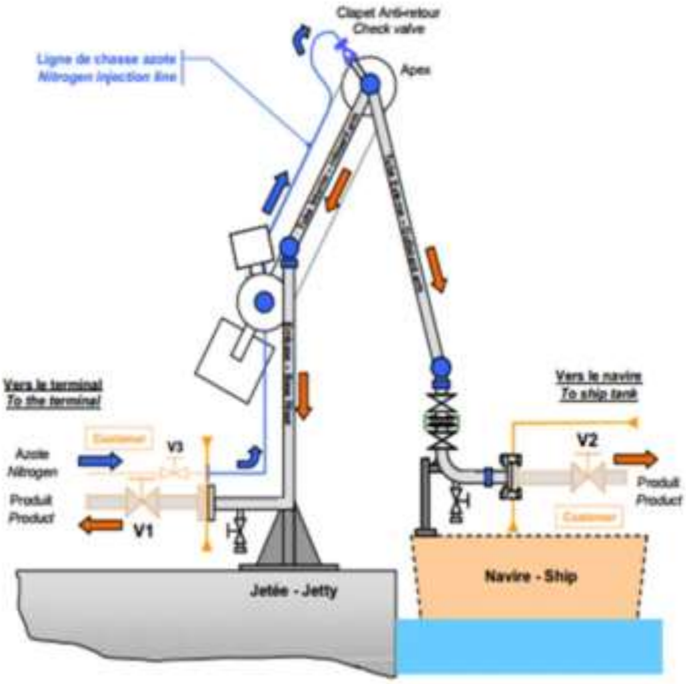


Figure 1: The loading arm to aid in transportation of liquid cargo from the wharf (Anup, K. D., n.d.).

Failure Mode of Loading Arm

Failure of the loading arm will cause the liquid to leak or release to the atmosphere (Table 3). In order to determine the amount of release, thus the failure mode had to be determined. The area of hole of release will determine the flow rate and the pressure of the liquid into the atmosphere. HSE Executive, UK had summarized and determine that the failure mode are

guillotine failure, that is the liquid release with the area of the cross sectional area of the pipe, and 0.1 of the cross sectional area of the pipe. (Health and Safety Executive, 2017) This will be the basis to determine the flowrate of the liquid into the atmosphere. The ammonia properties to be included in determining the flowrate are the operational pressure of 6 Bar, Atmospheric pressure of 1 Bar, the liquid temperature of -33 ^{o}C. Specific gravity of 0.681 for ammonia (Kaczmarek et al., 2014)
The leak rate equation is:-

$Q = CA\{2AP/(SPw,std)\}^{-1/2}$
A = area of hole or crack
C = Discharge coefficient, need $0<C<1$
S = Liquid specific gravity.
P = water sp
ΔP = Pressure drops from inside to outside of pipe (N/m^2)
Q = Flowrate of the leak in m/s

Table 3: Failure Mode Parameters for Loading Arm

Failure Mode	**Guillotine (Total cross-sectional area)**	**0.1 cross sectional area**
Diameter (m)	0.0762	0.0762
Area (m^2)	0.004558055	0.00045581
Pressure (Pa)	600000	600000
External Pressure (Pa)	100000	100000
Coefficient C	0.61	1.61
Discharge Rate Q (m^3/s)	0.106545688	0.01789871
Specific gravity	0.681	1.681

Metrological condition
Metrological data was obtained from Metrological Department Malaysia, and the wind data are as follows **(Table 4).**

Table 4: Metrological Conditions On 4 Scenarios of Ammonia Leakage from Metrological Department Malaysia Bintulu Station 2010-2019

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Wind Direction	East (E)	South-East (SE)	North-West (NW)	North (N)
Wind Speed (meter per second)	1.5	1.5	3.0	4
Pasquill atmospheric stability classes	F Stable	F Stable	E Slightly Stable	D Neutral
Temperature (oC)	35	35	35	35
Humidity (%)	80	80	80	80

Simulation Software

Various studies and various software had been used for simulation. For this study, ALOHA is use as it is free; thus, it is widely used by experts, organizations, and departments. Lee et al. indicated that ALOHA is the best simulator for the determination of ammonia toxicity (Lee et al., 2018). ALOHA based its simulation on Gaussian Distribution for the migration of vapour cloud. The simulation outputs for four scenarios shown in **Figure 2.**

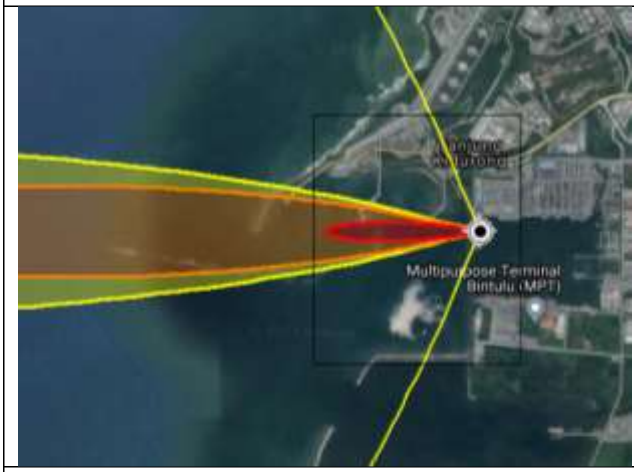
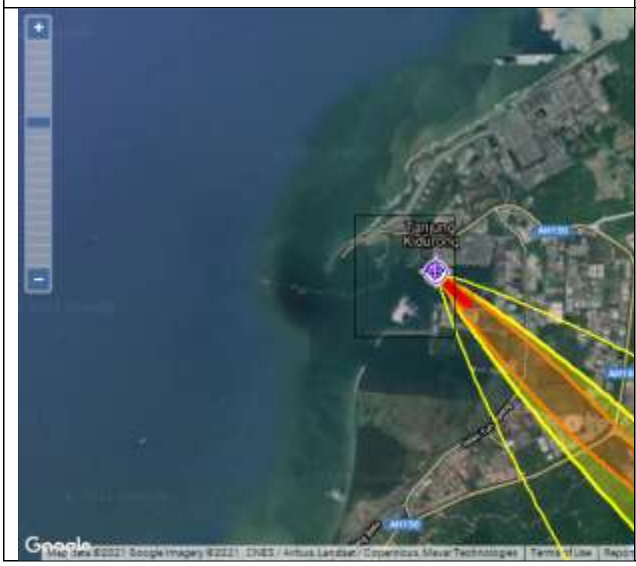
Scenario 1	**Scenario 2**
	
Scenario 3	**Scenario 4**
	

Figure 2: Simulated ammonia dispersion based on four scenarios from Table 4

Risk Assessment on Ammonia Release at The Port

Failure rates are a valuable tool for determining the viability of a plan or project, as well as for understanding the problem in the sector. People will have to weigh the threat against the mode of failure's projected failure rate. Risk assessment may be performed, and conclusions derived from this information and the consequence report as shown above through the three tiers.

Probability of Failure

The probability of incident as illustrated by HSE Executive for single loading arm (Health and Safety Executive, 2017) as follows: -

- Guillotine failure: 7 x 10-6 per operation
- 0.1 Cross sectional area of pipe: 8 x 10^{-6} per operation

Guillotine Break

Failure rate for guillotine break is 7 x 10^{-6} per transfer.
For a monthly transfer, for 3 days per year, the probability of failure is
3/365 x 12 x 7 x 10^{-6} year = 6.9 x 10^{-7} per year

Hole = 0.1 cross sectional area of pipe

Pipe diameter = 3 inches = 750 mm.
Failure rate for one arm = 8 x 10^{-6} per year
One 3-day operation per month will have the failure rate of 3/365 x 12 x 8 x 10^{-6} = 7.89 x 10-7 per year

Risk of the event (Probability of Loss of Life)

For the four scenarios, the risk is summarised as below (Table 5): -

Table 5: Individual Risk Based on 4 Scenario of Failures

Parameters	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Failures	Guillotine	0.1 Cross Sectional Area	Guillotine	0.1 Cross Sectional Area	Guillotine	0.1 Cross Sectional Area	Guillotine	0.1 Cross Sectional Area
Population	100	100	100	100	181	181	181	181
Probability x 10^{-7} per year	6.9	7.89	6.9	7.89	6.9	7.89	6.9	7.89
Percentage of wind direction (%)	24.9	24.9	21.1	21.1	12.0	12.0	9.6	9.6
Individual Risk X 10^{-5} per year	1.71	1.96	1.45	1.66	1.49	1.71	1.19	1.37

This is an estimate that the toxicity of ammonia within the area is below the mortality rate. HSE Executives UK's Individual Risk Criteria (Det Norske Veritas,2002) provide guidelines on acceptable limit.

- Maximum tolerable risk for workers 10^{-3} per person per year
- Maximum tolerable risk for public 10^{-4} per person per year

It is thus concluded that the risk using the loading arm with the current control is acceptable.

Conclusion

Simulation software support management in determining the acceptable control measure taken for ammonia loading in the port. The simulation software requires metrological data and operational data to provide simulated zones of interest. Using ALOHA which is free and acceptable to be used to simulate ammonia release gives zones in AEGL. This study will be considering the individual tolerable risk. Using a loading arm as the mode of transfer of ammonia from land to vessel, it was indicated that the process it is below the tolerable risk for workers and the public based on failure mechanism as indicated by HSE Executives. Future research should focus on operational failures, such as leakage, which are more likely to occur (Vílchez et al., 1995). The programme will make it easier to figure out how much leakage there is and where the areas of concern are (Haastrup & Brockhoff, 1990).

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