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Risk Assessment of Liquid Ammonia Loading Process at Petrochemical Company Docks

Nindio Mahendra[1)], Hilda Gloria Natalia Tanggu Hunga[1)], Putri Dyah Setyorini [1,*)], Dhimas Widhi Handani[1)], A.A.B. Dinariyana Dwi Putranta [1)]

[1)] Department of Marine Engineering, Faculty of Engineering and Marine Science, Universitas Hang Tuah, Surabaya 60111, Indonesia

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Correspondence Author:
Putri Dyah Setyorini
putridyahs@gmail.com

ABSTRACT

This study addresses a risk assessment at the terminal facility of a petrochemical company. Hazards are identified using HAZOP (hazard and operability), while the frequency of hazards is determined by means of fault tree and event tree analysis. The consequences of hazards are analyzed using process hazard analysis tools, and risk is represented in the F-N curve according to Hong Kong Government Risk Guidelines (HKRG). Five leak diameter scenarios were examined, resulting in two hazards that could potentially occur during the ammonia loading process: gas dispersion and explosion. According to the result of frequency and consequence analysis, those hazards are located in the ALARP (as low as reasonably practicable) region; hence, there is no mitigation necessarily to be taken. However, for safe operation, the company should ensure that the risks will not move to an unacceptable level by performing routine maintenance and that all safety procedures established by the company are well implemented.

Keywords: *societal risk assessment; ammonia loading facility; HAZOP; f-n curve.*

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1. INTRODUCTION

Ammonia is an important NH_3 nitrogen compound and is widely produced as the main raw material for fertilizers and has an important contribution to the existence of nutrients on earth, ammonia is a caustic compound and ruin health. Contact with high concentrations of ammonia gas can cause lung damage and even death. Although ammonia is regulated in the United States as a non-combustible gas, it is classified as toxic by inhalation, and the transport of ammonia in amounts greater than 3,500 gallons (13,248 l) requires a license.

The Indonesian government through the Minister of Health of the Republic of Indonesia Decree Number 1405/MENKES/SK/XI/2002 stipulates the ammonia threshold is 25 ppm (part per million) or 17 mg/m^3. Inhaling ammonia at high concentrations can cause swelling of the respiratory tract and shortness of breath and exposure to 0.5% concentrations for 30 minutes can cause blindness.

In its utilization, petrochemical companies often produce and sell ammonia in liquid form, which is transported in large quantities using chemical tankers. In the process of loading ammonia from storage tanks to ships, there is the potential for several hazards to occur which can damage the environment, while high levels of ammonia have the potential to have a fatal impact if exposed directly to humans. On October 27, 2015, two people died due to ammonia gas poisoning from the hatch of KM Orai which leaned on the port of Panjang, Lampung (Harian Lampung, 2015). An ammonia gas leak during loading was reported in 2014 at a Port of Ukraine

(ICIS News, 2014) and in 2018 a similar incident also occurred at the Kwinana Beach Jetty Terminal where a small amount of ammonia leaked during the unloading process of ammonia from the ship to the storage tank ammonia (Campbell, K. & Zimmerman, J., 2018). This incident is the reason for carrying out a risk assessment due to ammonia leakage and its impact on humans. This study discusses the risk assessment of the process of loading liquid ammonia from storage tanks on land to ships transporting liquid ammonia through dock facilities.

Risk assessment is a common method used before a facility is built and operated to define the hazards that could potentially occur during construction and operation. It is also common for risk assessments to be carried out for facilities that are modified after they are operational, where the age of the facility can pose a risk to both the company and the environment. There are many cases where the risk assessment carried out does not take into account the developments that occur around the facilities being built, including the development of settlements that are close to existing facilities so that the risk profile might change from the initial conditions.

Production and distribution facilities for chemicals, hydrocarbons and hazardous liquid products are believed to have potential hazards that have financial, health, safety, environmental impacts and company reputation impacts known as HSE (health, safety, environment). Risk studies of chemical and hydrocarbon production facilities at the facility design stage have been published by (Krisna, I.W.G., et al, 2018), (Setyorini, P.D., et al, 2018), and (Krisna, I.W.G., 2018). In studies conducted by: (Setyorini, P.D., 2015) and (Dinariyana, A.A.B, et al, 2013) explained the risks at the construction and development stages of facilities, (Setyorini, P.D., 2015) discussed the risks to underwater gas pipelines that there has been a result of installing the tie-in spool at the construction stage of the new gas facility using a mooring vessel. Meanwhile (Dinariyana, A.A.B, et al, 2013) said about the risk assessment of underwater gas pipelines due to dredging activities in the development of the anchor area adjacent to the existence of the pipeline. Studies of underwater gas pipelines as a result of the operation of ships passing above them can be found in (Pratiwi, E. et al, 2018) and (Pujianti Pujianti Widhiastuti, N.L.P., 2019). Several social risk assessment studies due to leaks that have the potential to occur in petrochemical and hydrocarbon facilities can be found in studies conducted by (Akbar, T.A., et al, 2018), (Dedy W. Putra, 2019), and (Prajna, N.P., 2019). In this study, as with the last three references, risk assessment due to ammonia gas leakage in the process of unloading ammonia from storage tanks to tankers is the focus of the study.

Risk assessment begins with hazard identification to determine the potential hazards that can occur when loading ammonia from storage tanks to ships. For each hazard that has been identified, the value of frequency and consequences is calculated to determine the level of frequency and impact on humans and the environment if it occurs. The risk level is determined by breaking the frequency and consequence levels that have been calculated in the F-N Curve which refers to the Hong Kong Government Risk Guidelines (HKRG) standard where the F-N curve functions to determine whether the resulting hazard is still at an acceptable risk level or not. Mitigation will be carried out if the risk is at an unacceptable level. One of the mitigation methods that can be used is LOPA (Layer of protection analysis).

2. METHOD

2.1. Petrochemical Company Facilities

Risk assessment on the process of loading ammonia at the wharf from the liquid ammonia storage tanks on land to the tanks on board. The process at the ammonia plant includes ammonia loading process as shown in the process and instrumentation diagram (P&ID) in Figure 1.

The ammonia storage tank has a very low-level alarm and a very high-level alarm which functions as a safety instrumented system. When an alarm trip occurs at a very low-level alarm, the level indicator controller will send a signal to instruct the transfer pump to stop thereby stopping the transfer of ammonia taken from the ammonia storage tank. The very low-level alarm on the minimum storage tank is designed with a height of 120 cm from the bottom of the tank, this is intended to prevent ammonia voids from occurring which can affect pump work. Whereas for a high-level alarm, when a trip alarm occurs, it will send a signal to the transfer pump which distributes liquid ammonia to the ammonia storage tank to stop and also closes the control valve on the ammonia distribution pipe leading to the storage tank.

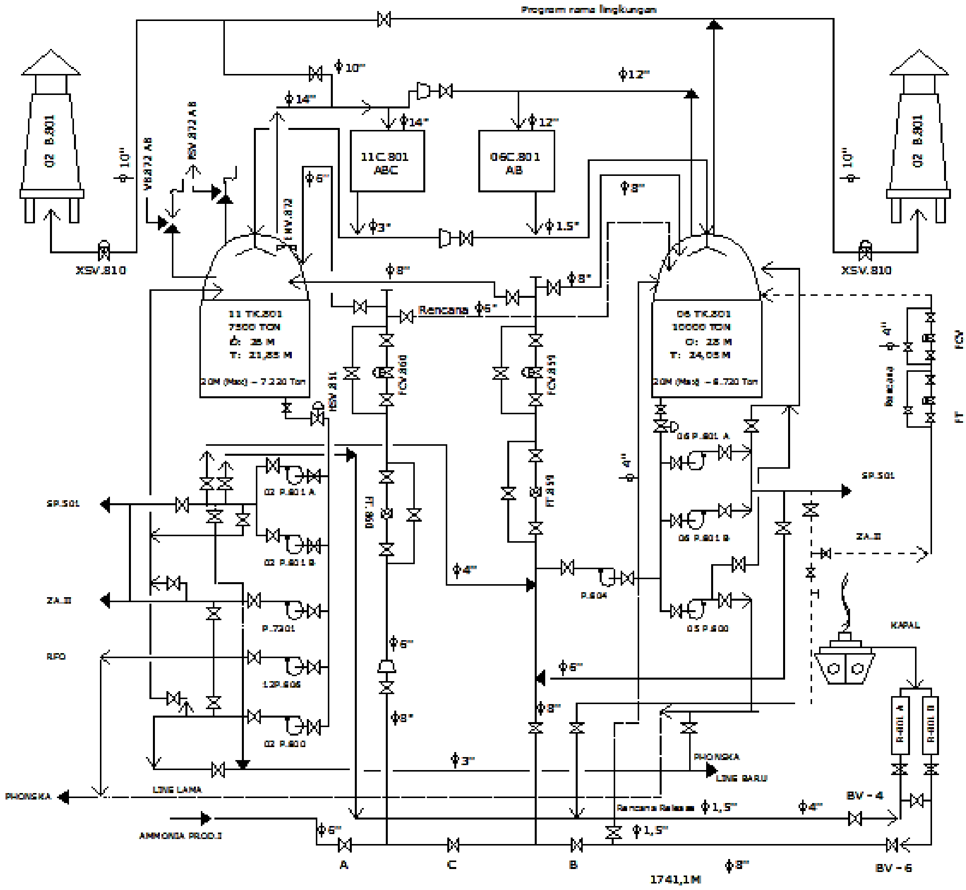


Figure 1. Process and Instrumentation Diagram of Ammonia Plant

In the process of controlling the level that occurs in this storage tank, it is also influenced by variable pressure, so that this storage tank also has a low-pressure indicator and a high-pressure indicator installed. The pressure reference under normal process conditions is in the range of 20 gr/cm^2 – 70 gr/cm^2, and the pressure control system in the tank is when the pressure variable reaches 45 gr/cm^2 it will activate compressor 1 automatically, then when the pressure reaches 60 gr/cm^2 it will activate compressor 2 and when the pressure reaches 75 gr/cm^2 it will automatically activate compressor 3.

In the process control system in this storage tank, there are 3 compressors which aim to maintain the stability of the pressure value when there is a fluctuation in the pressure value. If the pressure value continues to rise to 90 gr/cm^2, the ammonia vapor will be burned by the ammonia incinerator so that the ammonia pressure can decrease until the process returns to stability (Kurniasari, 2009). To prevent the temperature, rise due to the outside air, the outside of the ammonia tank wall is covered with insulation in the form of foam glass 15-17.5 cm thick.

The tank is equipped with a refrigeration system, to prevent the increase in tank pressure due to evaporation. Ammonia vapor from the tank is sucked in by the compressor and flowed through the surge drum before being pressed. Surge drum is an ammonia vapor separator tank with liquid ammonia which is sucked in by the compressor. Ammonia vapor from the drum is channeled into the compressor, while liquid ammonia is channeled into the tank. In the compressor, ammonia vapor mixes with the oil used in compression. The oil is separated from the ammonia vapor as a result of pressure on the oil separator. Ammonia vapor will go to the tank, while the oil is cooled by the oil cooler. Ammonia vapor from the oil separator is separated once again from the remaining oil with an extra oil separator. The separated oil returns to the compressor to raise the compressor oil level. Meanwhile, the separated ammonia vapor is flowed into the condenser. Ammonia vapor with high pressure and temperature is liquefied here with water as the cooling medium. Ammonia vapor enters the shell side, while water enters through the tube side. The resulting liquid ammonia is flowed to the receiver, from the receiver, part of the liquid ammonia is expanded through the valve so that the temperature drops and is flowed to the economizer shell side and becomes coolant, some is flowed to the tube side through the valve to be cooled. In the economizer, liquid ammonia is lowered to -33°C. Liquid ammonia with a temperature of –33°C is returned to the tank, while ammonia vapor that occurs in the shell due to heat absorption returns to the compressor. The air that is involved in the process all enters the air purged to be absorbed from the free ammonia content and then discharged into the outside air (Z.Z, 2016).

The loading and unloading wharf have a trestle and jetty structure where the wharf can accommodate three ships weighing between 40,000 dwt and 60,000 dwt simultaneously on the sea side and 10,000 dwt on the land side. The jetty has a capacity of 60 tonnes/ hour for liquid ammonia unloading facilities.

2.2. Methodology

In general, the social risk assessment method in the ammonia loading process is carried out in several stages including hazard identification, frequency analysis, consequence analysis, risk determination, mitigation if the risk is at a level not acceptable.

Hazard identification uses the Hazard and Operability (HAZOP) method in identifying the hazards of a system or process, using the keywords: How, Low, No, etc. to find out the deviation of the system or process based on predetermined parameters such as pressure, temperature, flow, etc. The HAZOP method is more widely used to evaluate or identify hazards at the system level with a qualitative approach. Quantitative approaches are also often found, and are widely used to identify hazards and the operability of a continuous system or process, especially fluid or thermal systems or processes used to identify hazards (Artana, K.B., et al, 2013). The HAZOP process is carried out in the following stages:

a. Understanding system processes, starting from the system in the ammonia plant to the system on board.
b. Understanding the operation of each equipment in the system.
c. Defining each existing system, then dividing it nodes.
d. Identify deviations at each node.
e. Identify causes and consequences at each node.
f. Identify existing safeguards.
g. Fill in the HAZOP table with BS IEC standard 61882:2001 (British Standard, 2001).

Referring to the potential hazards that have been identified from the HAZOP process, frequency analysis is used to determine how often the hazard occurs. The frequency level is represented by the number of events in one year. The methods used in frequency analysis are Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). The FTA is used to calculate the frequency of occurrence of leaks at the studied facility and the results of the FTA are then used as input for the ETA study to obtain the frequency value of the occurrence of identified hazards, such as the frequency of gas dispersion or explosions due to leaks that occur. Consequence analysis is carried out to determine the impact or magnitude of the hazard that has been identified. In this study, consequences are modeled using a process hazard analysis approach.

Based on the frequency and consequence analysis that was carried out, then the frequency and consequence values were mapped onto the risk curve to determine the risk level of the identified hazard. The risk curve used is the F-N curve referring to the Hongkong Government Risk Guidelines (HKRG) standard, (EIA Report, 2006). Furthermore, based on the level of risk obtained, mitigation is only carried out if the risk is at an unacceptable level.

3. RESULT AND DISCUSSION

3.1. Hazard Identification and Frequency Analysis

In the HAZOP study, P&ID was divided into three nodes referring to the existing sub-systems in the ammonia loading process. The three nodes are: 1) discharge system (ammonia is transferred from storage tanks to ships), 2) transfer system (ammonia is transferred from storage tanks to ships through manifolds on the docks and ships), and 3) receiving system (ammonia to tanks). on the ship). Based on these nodes, then determine the deviations that occur in the system, the causes and consequences of the deviations, determine the safeguards or instruments that must be installed to carry out early detection of deviations that occur, and propose the necessary actions for each deviation that occurs. Table 1 shows the HAZOP process at node 3 (receiving system). In table-1, there are several events that result in the dispersion of ammonia gas, one of which is valve blocked and pump failed. To prevent this condition from happening, the safeguard installed is a pressure safety valve. Undesirable over pressure conditions is indicated by "not acceptable" in the "comment" column. It can be concluded that node 3 (receiving system) will fail if valve is blocked and pump failed.

Tabel 1. HAZOP *Receiving System Ammonia*

No	Guide Word	Deviation	Possible Causes	Consequence	Safeguard	Comments	Action Required
1	No	No Flow	Valve COV 309 Block Valve COV 201 Block Valve COV 025 Block Valve TCV 001 Block Valve TCV 002 Block Valve COV 076 Block Pump SP Failed Valve COV 087 Block Valve COV 104 Block Valve COV 173 Block Valve COV 141 Block	No ammonia Supply	Flow Meter	No Acceptable	Routine Check Equipmen t
2	Mor e	More PR	Valve COV 309 Block Valve COV 201 Block Valve COV 025 Block	Dispersion Toxic Flash Fire	Pressure Safety Valve	No Acceptable	Routine Check Equipmen t

	Valve TCV 001 Block Valve TCV 002 Block Valve COV 076 Block Pump SP Failed Valve COV 087 Block Valve COV 104 Block Valve COV 173 Block Valve COV 141 Block	

This study conducted five leak hole scenarios, such as: 1-3 mm leak hole; 3-10mm; 10-50mm; 50-150mm; and rupture with a leak hole of more than 150 mm. From the HAZOP analysis of the three nodes, two potential hazards can occur during the ammonia loading process, namely gas dispersion and vapor cloud explosion (VCE). Furthermore, frequency analysis to determine how often the occurrence of leaks will occur during the ammonia loading process. Failure rates for failure modes on valves, pumps, and pipes are obtained from OREDA data (Sintef, 2002). Figure 2 and table 2 provide an example for FTA at node 3 with a leak hole scenario of 50-150 mm, the annual frequency of leak holes is 1.4798 x 10-4. Table 2 shows the FTA results for the three nodes with five variations of leak holes.

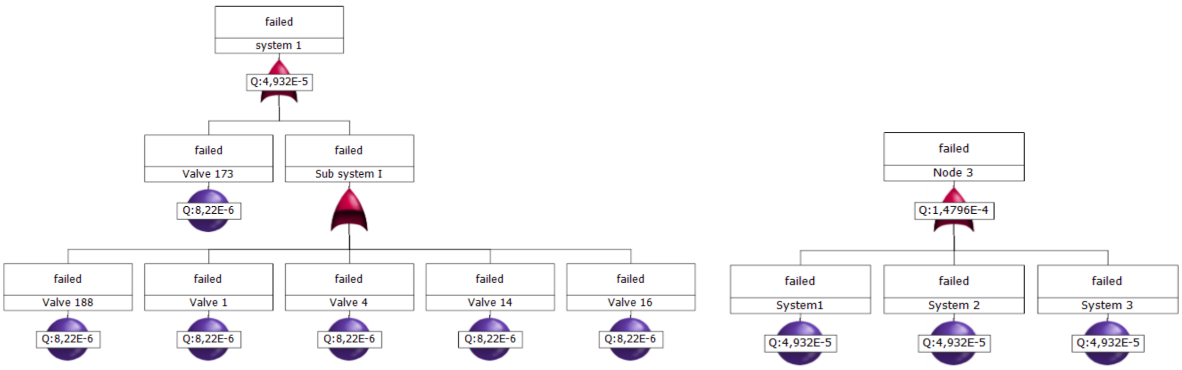


Figure 2. FTA at Node 3 with 50-150mm Leak Holes

Table 2. FTA on All Nodes

Node	Failure Rate				
	(1-3mm)	**(2-10mm)**	**(10-50mm)**	**(50-150mm)**	**>150mm)**
1 – Discharge	4.11x10^{-4}	1.90x10^{-4}	9.06x10^{-4}	5.27x10^{-4}	-
2 - Transfer	0.00351	0.00111	3.38x10^{-4}	4.93x10^{-4}	8.13x10^{-4}
3 - Receiving	0.00105	0.00332	0.00101	1.48x10^{-4}	2.44x10^{-4}

ETA is done by outlining the top events of the FTA. Gas release (gas release) due to a leak is the top event of an incident, then identified hazards that might occur if the ammonia gas released is exposed or not to heat/fire. In the Receiving System, ammonia that comes out of the tank and is exposed to fire can result in an explosion, while gas dispersion will occur if the ammonia gas that comes out is not exposed to heat or fire. Figure 3 provides an overview of the

ETA where the frequency of explosions with 50-150 mm leak holes is 1.48×10^{-5} while the frequency of ammonia gas dispersions is 1.33×10^{-4}. Meanwhile, table 3 describes the frequency of gas dispersion using ETA, while table 4 describes the frequency of gas explosions using ETA.

	Ignition	*Explosion*
Gas release	0.1	1.48×10^{-5}
1.48×10^{-4}	*No Ignition*	*Gas dispersion/toxic*
	0.9	1.33×10^{-4}

Figure 3. ETA at Node 3 with Leak Holes 50-150 mm

Tabel 3. ETA *Gas Dispersion Toxic*

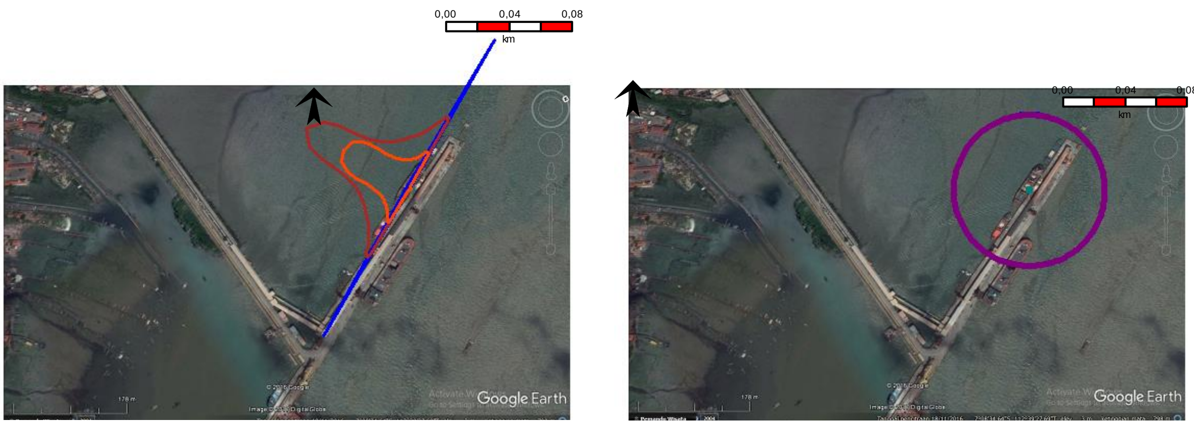
Node	Failure Rate				
	(1-3mm)	(2-10mm)	(10-50mm)	(50-150mm)	>150mm)
1 – Discharge	3.70×10^{-4}	1.71×10^{-4}	8.15×10^{-5}	4.74×10^{-5}	
2 - Transfer	3.16×10^{-3}	9.97×10^{-4}	3.04×10^{-4}	4.44×10^{-5}	7.32×10^{-5}
3 - Receiving	9.47×10^{-4}	2.99×10^{-3}	9.11×10^{-4}	1.33×10^{-4}	2.16×10^{-4}

Tabel 4. ETA *Gas Explosion*

Node	Failure Rate				
	(1-3mm)	(2-10mm)	(10-50mm)	(50-150mm)	>150mm)
1 – Discharge	4.11×10^{-5}	1.90×10^{-5}	9.06×10^{-6}	5.27×10^{-6}	
2 - Transfer	3.51×10^{-4}	1.11×10^{-4}	3.38×10^{-5}	4.93×10^{-6}	8.14×10^{-6}
3 - Receiving	1.05×10^{-4}	3.32×10^{-4}	1.01×10^{-4}	1.48×10^{-5}	2.40×10^{-5}

3.2. Consequence Analysis

The considerations used in the consequence analysis to see the impact are, the capacity of storage tanks on land and cargo space on ships, the number of people/operators around the ammonia loading terminal facility. Other data on environmental conditions include: humidity, wind speed, wind direction. With humidity of 75.2% and three variations of wind speed (1.3 knots; 7.3 knots; 9.3 knots) and the wind direction is Northwest, Figure 4a is the distribution of ammonia gas if there is a leak of 150 mm at node 3 (Receiving System). The distribution of ammonia gas has a radius of 157.14 m at a wind speed of 9.3 knots which is shown with a red curve. The lower the wind speed, the smaller the distance the ammonia gas will spread. Figure 4b shows the explosion radius if the ammonia that comes out is exposed to fire.



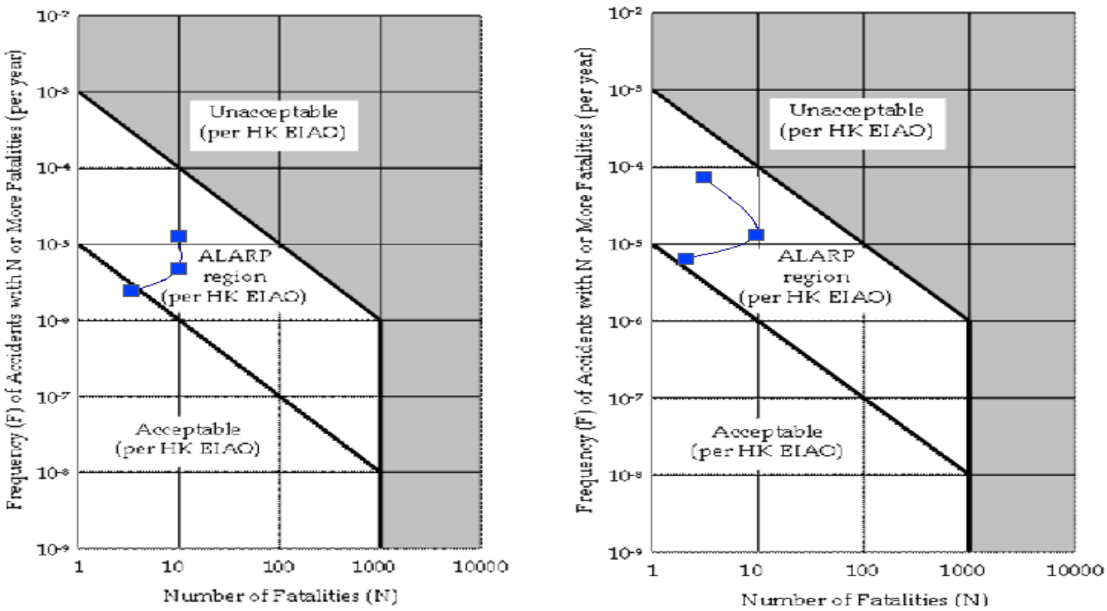
(a) (b)

Figure 4. (a) Distribution of Ammonia Gas, (b) Explosion Radius

Based on the layout of the facilities and the distribution of operators and workers, the explosion scenario for all cases of leak holes did not find any casualties. Whereas in the case of dispersion of ammonia gas with ammonia levels of 5000 ppm, there were cases of death in humans.

3.3. Risk Representation

Refer to HKRG standard. Risk mapping due to gas dispersion that occurs in 50 mm and 150 mm leak holes is in Figure 5. (a) the frequency of occurrence of 50 mm leak holes is greater than 150 mm but on the other hand, 150 mm leak holes have an impact on the number of deaths which is more. It can also be seen that cumulatively for the three nodes, the risk is in the ALARP area. Table 5 provides an analysis of the frequency of leaks for several variations of leak holes and the results of the consequence analysis for variations of leak holes and for the nodes studied in this study. The risk representation for all leak holes is in the ALARP area, this condition is contributed by the small frequency value and the large number of victims. In practice, in ALARP conditions the risk is still acceptable as long as the company can maintain the value of the frequency of occurrence of leaks without moving to a larger value.



(a) (b)

Figure 5. Risk representation (a) 50mm leak hole, (b) 150mm leak hole

Tabel 5. ETA *Representasi resiko*

	Skenario	Probability Gas Dispersion	Number of victims (N)	ZONA
3mm	NODE 1	3,70E-04	3	ALARP
	NODE 2	3,16E-03	5	
	NODE 3	9,47E-04	5	
10mm	NODE 1	1,71E-04	3	ALARP
	NODE 2	9,97E-04	5	
	NODE 3	9,11E-04	5	
50mm	NODE 1	8,15E-05	15	ALARP
	NODE 2	3,04E-04	10	
	NODE 3	1,33E-04	10	
150mm	NODE 1	4,74E-05	19	ALARP
	NODE 2	4,44E-05	10	

	NODE 3	2,16E-04	10	
200mm	NODE 1	4,74E-05	19	ALARP
	NODE 2	7,32E-05	10	
	NODE 3	2,16E-04	10	

During the ammonia loading process, two potential hazards were identified, are: gas dispersion and gas explosion hazard at the loading dock. Gas dispersion and explosion that has the potential to occur, are caused by: increased pressure due to work failure on one of the equipment serving the loading process. Gas dispersion with levels of 5000 ppm resulted in casualties and the largest explosion of ammonia gas gave an explosion magnitude of 3 psi which did not have an impact on the occurrence of casualties. The distribution of gas with ammonia gas levels of 100 ppm, 700 ppm and 5000 ppm resulted in minor injuries to death. The risk is in the ALARP area where this condition is practically acceptable as long as the company can maintain the frequency of occurrence of leaks. No mitigation is required and it is recommended to maintain the frequency level of leaks by carrying out periodic maintenance.

4. CONCLUSSION

Based on studies that have carried out an assessment of the risk of loading liquid ammonia at the wharves of petrochemical companies, it is concluded that: the hazards that occur are gas dispersion and explosions caused by work failure on one of the equipment. Gas dispersion at 5000 ppm resulted in fatalities, and a 3-psi gas explosion did not result in fatalities. Ammonia levels have different effects on humans, the amount depends on the level of ppm and the area of distribution where the higher the concentration of ppm and the small area of distribution can result in death. As long as the system can maintain the frequency of leaks by carrying out routine system maintenance, the risk of gas dispersion and gas explosion can be avoided.

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