ALOHA SIMULATION TO DETERMINE CONSEQUENCE SCENARIOS ON TRANSPORTATION *LIQUEFIED NATURAL GAS* (LNG) IN DKI JAKARTA PROVINCE

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Abstract

The mobility of using LNG is based on its advantages as a substituent fuel for gasoline and diesel, where LNG has low emission properties. The process of mobilizing the distribution of LNG has the potential for accidents when it takes place. The study was conducted to determine the hazards that can occur and the safe distance for evacuation in the event of a leak using ALOHA simulation. The research process is carried out by studying literature, collecting data, determining the month and time of release, and continuing with a simulation of the existing data. The data analysis technique was carried out by determining the tank temperature and water dispersion model at 31 SPBG. Fireball simulation results at 8:00 a.m. 2:00 p.m, and 10:00 p.m have safe distances at 812 meters, 812 meters, and 815 meters. Fire column simulation results at 8:00 a.m. 2:00 p.m, and 10:00 p.m have safe distances at 29 meters, 29 meters, and 28 meters. Vapor cloud simulation results at 8:00 a.m. 2:00 p.m, and 10:00 p.m have Lower Explosive Limits (LEL) at 169 meters, 160 meters, and 243 meters. Thus the ALOHA simulation can represent the safe distance of evacuation and scenarios in the event of an accident.

Keywords: *ALOHA, BLEVE, LNG, safe distance*

Introduction

Liquefied natural gas (LNG) is one of the alternative fuels that have the potential to be used in Indonesia. Indonesia is a country that has abundant natural gas resources. This is shown from the Central Statistic Agency (BPS) Statistical Review of World Energy, in 2019 natural gas reserves in Indonesia amounted to 50.5 trillion standard cubic feet (TSCF). (BP, 2020). With a large number of natural gas reserves and fixed production capacity, LNG can be used as an alternative fuel in Indonesia and can reduce gasoline and diesel consumption. Besides still Due to a large number of natural gas reserves in Indonesia, LNG can also be used as transportation fuel, especially in DKI Jakarta Province. This is indicated by the availability of Gas Fuel Filling Stations (SPBG) in DKI Jakarta Province. Based on data obtained from Dinas Tenaga Kerja, Transmigrasi dan Energi, there are 31 SPBGs with 19 operating SPBGs and 12 non-operating SPBGs. (Dinas Tenaga Kerja Transmigrasi dan Energi, 2020). LNG can be distributed using land transportation and water transportation modes. But to reach consumers, distribution is needed by land transportation modes. The advantages of the land transportation mode are lower production costs, while the weakness is the potential for leakage during transportation. Characterization of potential hazard must be conducted in all such

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companies (Aryanto et al., 2021). The aim of this study is to determine the dangers that can occur for humans and the environment as well as a safe distance for evacuation in the event of an LNG leak and scenarios using ALOHA simulations.

Liquefied natural gas (LNG) is an odorless, colorless, non-toxic, and non-corrosive product produced from natural gas. The main constituent components are methane (87% - 99%), ethane, propane, butane, and other heavy hydrocarbons. In addition, LNG contains Nitrogen, carbon dioxide, water, and compounds trace other (BP Process Safety Series, 2007). One of the uses of LNG that can be developed in Indonesia is as an alternative fuel to replace diesel or gasoline. From an environmental perspective, compared to diesel and gasoline, LNG produces 23% lower CO2 emissions per unit of energy (NFPA 59A, 2013), 90% lower yield of NO_x compounds, and almost 100% does not produce particulate emission and SO. compounds (Herdzik, 2011). Meanwhile, from the technical aspect, LNG has a high octane number, which is 120+ compared to gasoline 84–93. LNG vapor has a temperature of auto-ignition (AIT) which is higher at 540ºC compared to diesel which is only 316ºC and gasoline at 257ºC so it is safer to use (Kumar, H, Choi, & Lim, 2011). However, the energy content is lower than diesel and diesel, namely 19 MJ/liter, 35 MJ/liter, and 32 MJ/liter (Maxwell & Jones, 1995).

LNG still has dangers that can occur during the process of storage, distribution, as well as loading and unloading activities. Vapor clouds and vapor dispersion due to a large LNG accident, fire due to LNG is a highly flammable, highly explosive compound, fire is very easy to spread, the rate of combustion is twice that of gasoline combustion and has a high flame temperature so that it produces radiant heat. The large ones in Table 1 below describe the magnitude of the flux value and the hazard caused, an explosion where the explosion will produce overpressure whose effects will be described in Table 2, and Boiling Liquid Expanding Vapor Explosion (BLEVE) is an explosion caused by a tank failure where the stored liquid has a temperature above its boiling point at atmospheric pressure (AIChE/CCPS, 2010).

Table 1 Hot flux and its dangers (BP Process Safety Series, 2007)

No	Heat Flux BTU/hour ft ^{2}	Danger
1	1,600 (5kW/m ^{2})	If exposed to humans, it will cause pain in 15 - 30 seconds, not harmful to humans
2	4,000 (12 kW/m ^{2})	*Combustible material* can catch fire when exposed to heat for a long time
3	6,700 (21 kW/m ^{2})	Buildings can catch fire if exposed to heat for a long time
4	10,000 (32 kW/m ^{2})	Steel in buildings will lose its strength.

Table 2. Criteria for overpressure (overpressure) (NFPA 59A, 2013)

Category	Overpressure (N/m2)	
	Lower limit	Upper limit
Broken window glass	250	4,000
Danger to doors, walls and people	5,000	10,000
Damaged building	15,000	20,000
Buildings were destroyed and people were seriously injured	25,000	50,000

ALOHA is software which is useful for planning and responding to chemical emergencies such as hydrocarbons. By using software ALOHA makes it possible to enter details about the presence of a potential chemical release and will then generate a zone estimate of threats to various types of hazards (Shao & Duan, 2012).

Methodology

Research Location

The research was carried out in DKI Jakarta Province

Tools and Materials

The type of data used in this research is secondary data. Secondary data is data obtained from various literature sources.

The data collection method in this study begins with identifying the month of what which will be a simulation of the occurrence release and take samples of what is vulnerable in the morning, afternoon, and evening. After identification, data collection is carried out.

The experimental design used in this study was derived from various data sources. The data required include:

1. Wind velocity
2. Wind direction
3. Humidity
4. Temperature
5. *Stability Class*
6. Tank diameter
7. Tank length

Data analysis technique

Determining the temperature in the tank

The tank temperature is determined at the start of the LNG release. The calculation of the temperature change during the release is determined by considering the thermal conduction through the tank wall in contact with the liquid and the evaporative cooling caused by the evaporation of the liquid in the tank to fill the void caused by the liquid leaving (cooling caused by adiabatic expansion in the tank is ignored). Calculation To calculate temperature changes during release contained in Equation (1) below

$$\frac{dT_T}{dt} = \frac{Q_e L_c + F_{Hw} A_{tw}}{\rho_l c_{pl} V_l} \quad (1)$$

Where,

F_{Hw} : heat energy flux across the wall

A_{tw} : the area of the tank wall in contact with the liquid

ρ_l, c_{pl}, V_l: density , heat capacity and volume of liquid in the tank

Evaporation rate at the head of the tank, Q_e, is simply related to the total mass loss of the tank, Q_T , and the effluent density, ρ_X, using the equation (2) :

$$Q_e(t) = \frac{Q_T}{\rho_X}\left(\frac{\rho_l \rho_g}{\rho_l - \rho_g}\right) \quad (2)$$

Where ρ_g is the density of the gas

Air dispersion model

Air dispersion models are essential for predicting the hazard zone associated with toxic or flammable gas clouds. This model is used to predict how pollutant concentrations, once released into the air, vary with time and position. Atmospheric turbulence has a major impact on the dispersion rate of pollutant clouds.

The model used to describe the dispersion of each cloud is based on the Gaussian dispersion model developed by Palazzi which describes the discharge behavior of conditions steady state with duration short[24] seen in equation (3)

$$.C(x,y,z) = \left\{\frac{X}{2}\left[\mathrm{erf}\frac{x}{\sigma_x\sqrt{2}}\right] - \mathrm{erf}\frac{x-Ut}{\sigma_x\sqrt{2}}\right\} \quad (3)$$

$(t \le t_r)$

$$C(x,y,z) = \left\{\frac{X}{2}\left[\mathrm{erf}\frac{x-U(t-t_r)}{\sigma_x\sqrt{2}}\right] - \mathrm{erf}\frac{x-Ut}{\sigma_x\sqrt{2}}\right\} \quad (4)$$

for $(t_r < t < \infty)$

Where,

$\sigma_x, \sigma_y, \sigma_z$ is dispersion parameters

t_r is release duration represent Gaussian distribution of discharge sources continuous steady state in equation (Hanna, Briggs, & Jr, 1982) .

$$X(x, y, z) = \left(\frac{Q(t)}{U}\right) g_y(x, y) g_z(x, z) \qquad (5)$$

where

$$g_y(x, y) = \frac{1}{\sqrt{2\pi}\sigma_y(x)} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y(x)}\right)^2\right] \qquad (6)$$

If there is no inversion,

$$g_z(x, z) = \frac{1}{\sqrt{2\pi}\sigma_z(x)} \exp\left[-\frac{1}{2}\left(\frac{z - h_s}{\sigma_z(x)}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + h_s}{\sigma_z(x)}\right)^2\right] \qquad (7)$$

h_r is release height

Potential hazards from toxic gases, flammable gases, BLEVE, jet fire, pool fire, and vapor cloud expansions can be modeled using ALOHA (Yang et al., 2019), (Bhattacharya & Kumar, 2015).

Result and Discussion

In fulfilling LNG needs in DKI Jakarta Province for land transportation, there are 31 gas filling station (SPBGs) consisting of 19 operating SPBGs and 12 non-operating SPBGs.

Based on SPBG data in DKI Jakarta Province, the location of the LNG release incident was taken at SPBG Kampung Rambutan.

Air Data

The air data was taken on December 8, 2021, during the rainy season. The data are shown at Table 3.

ALOHA Simulation

Fire Ball

In the first simulation is to determine the scenario of the fire ball for weather data at 8:00 a.m WIB

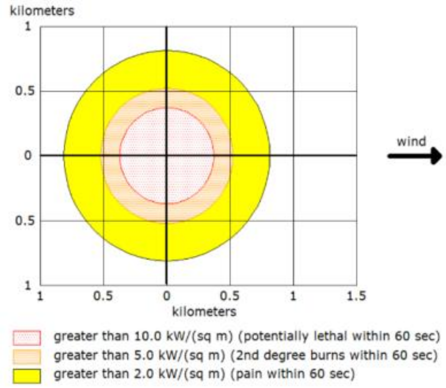

Figure 1 . Fire ball simulation on LNG spill at 8:00 a.m

Figure 2 . Mapping of locations affected by the LNG spill at 8:00 a.m at fireball review

Based on the results of the simulation carried out for the spill that occurred at 8:00 a.m as shown in Figure 1 and Pictures 2 It is known that radiant heat that can endanger drivers around with a leak in a tank truck of 1 inch is located at a radius of less than 370 meters with a radiant heat of more than 10 kW/m^2, while at a radius of 522 meters it can cause burns with a radiation heat of more than 5 kW/m^2, and at a radius of 812 meters can cause injury with radiant heat of more than 2 kW/m^2. It can be concluded from this first simulation, fire ball a safe distance for other drivers in the event of an LNG spill is more than 812 meters.

Table 3. Air data

Hours (WIB)	Wind Speed (meter/second)	Temperature (°C)	Humidity (%)	Wind direction
8:00	3.05	27	87	East
14.00	4.72	31	69	Northwest
22.00	1.67	25	91	Southwest

The simulation of determining the fire ball scenario for weather data at 2:00 p.m WIB, it was obtained that a fireball could be formed from an LNG spill that produced radiant heat as shown in Figure 3 and the coverage of the affected area from the point where the incident occurred as shown in Figure 4 .

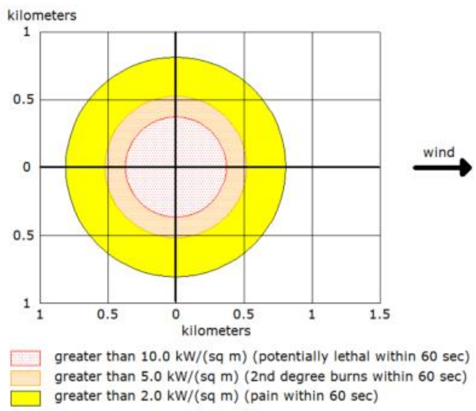

Figure 3 . Fire ball simulation on the LNG spill at 2:00 p.m

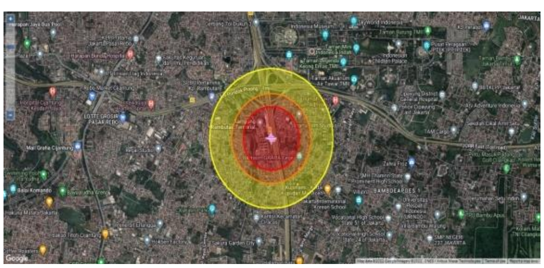

Figure 4 . Mapping of locations affected by the LNG spill at 2:00 p.m on the fire ball review

Based on the results of the simulation carried out for the spill that occurred at 2:00 p.m as shown in Figure 3 and Pictures 4 it is known that radiant heat that can endanger drivers around with a leak in a tank truck of 1 inch is located at a radius of less than 370 meters with a radiant heat of more than 10 kW/m^2, while at a radius of 522 meters it can cause burns with a radiation heat of more than 5 kW/m^2, and at a radius of 812 meters can cause injury with radiant heat of more than 2 kW/m^2. It can be concluded from this first simulation, fire ball a safe distance for other drivers in the event of an LNG spill is more than 812 meters.

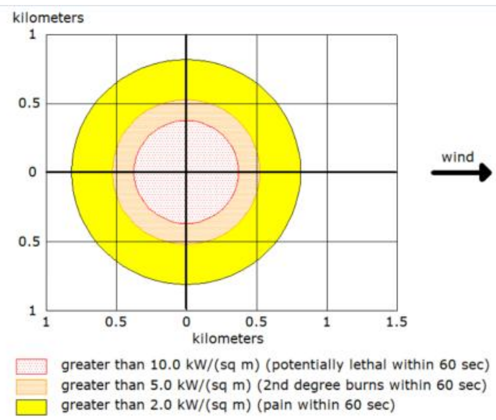

Figure 5 . Fire ball simulation on the LNG spill at 10.00 p.m

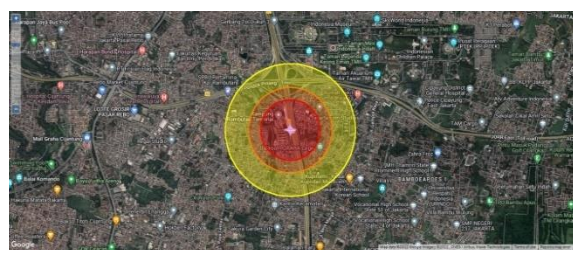

Figure 6 . Mapping of locations affected by the LNG spill at 10.00 p.m fire ball review

Based on the results of the simulation carried out for the spill that occurred at 10.00 p.m has shown in Figure 5 and Pictures 6 it is known that radiant heat that can endanger drivers around with a leak in the tank truck of 1 inch is located at a radius of less than 372 meters with a radiant heat of more than 10 kW/m^2, while at a radius of 524 meters it can cause burns with a large amount of radiant heat of more than 5 kW/m^2, and at a radius of 815 meters can cause injury with radiant heat of more than 2 kW/m^2. It can be concluded from this first simulation, fire ball a safe distance for other drivers in the event of an LNG spill is more than 815 meters.

Pool Fire

Pool fire can form from an LNG spill. Pool fire that is formed can generate heat around the source. The heat has an impact to the environment, especially for drivers who around the LNG transport truck.

Based on the results of the simulation carried out using weather data at 8:00 a.m are shown in Figure 7 and Pictures 8 It was found that at a radius of less than 11 meters it can produce radiant heat of more than 10 kW/m^2 which is dangerous for motorists around the location of the LNG spill. Meanwhile, at a distance of 18 meters, it only causes injuries to nearby drivers with a radiant heat of 2 kW/m^2. So it can be concluded that the safe distance (exclusion zone) in the event of an LNG spill is more than 29 meters.

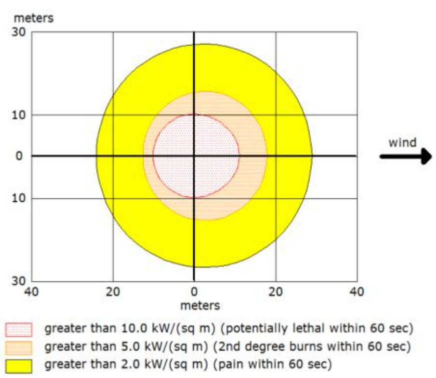

Figure 7 . Fire pool simulation on LNG spill at 8:00 a.m

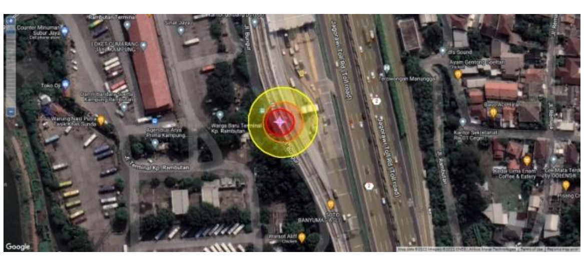

Figure 8 . Mapping of the location affected by the LNG spill at 8:00 a.m on the fire pool review

Fire pool scenario determination simulation fire for weather data at 2:00 p.m where the results are shown as in Figure 9 and Figure 10.

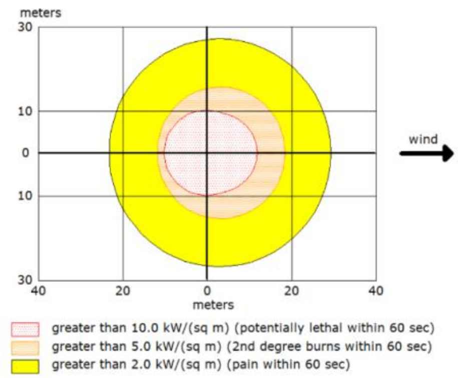

Figure 9 . Simulation of fire pool on LNG spill at 2:00 p.m

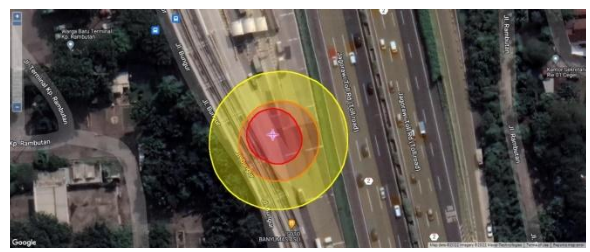

Figure 10 . Mapping of the location affected by the LNG spill at 2.00 p.m on the fire pool review

Based on the results of the simulation carried out using weather data at 2.00 p.m has shown in Fig 9 and Figure 10 it was found that at a radius of less than 12 meters it can produce radiant heat of more than 10 kW/m^2 which is dangerous for motorists around the location of the LNG spill. Meanwhile, at a distance of 19 meters, it only causes injuries to nearby drivers with a radiant heat of 2 kW/m^2. So it can be concluded that the safe distance (exclusion zone) in the event of an LNG spill is more than 29 meters.

The simulation of determining the fire pool scenario fire for weather data at 10.00 p.m WIB, it was obtained that a fire pool could be formed from an LNG spill that produced radiant heat as shown in Figure 11 and the coverage of the affected area from the point where the incident occurred as shown in Figure 12 .

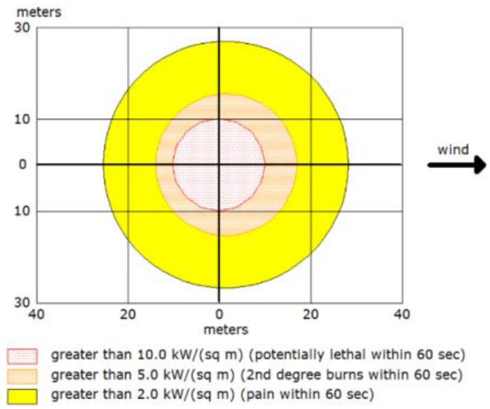

Figure 11 . Simulation fire pool on the LNG spill at 10.00 p.m

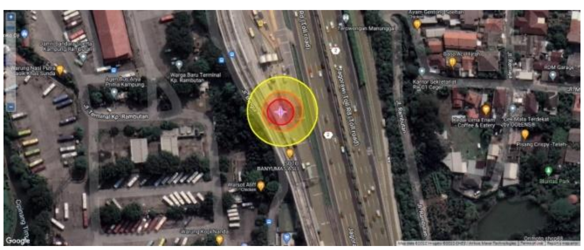

Figure 12 . Mapping of the locations affected by the LNG spill at 10.00 p.m fire pool review

Based on the results of the simulation carried out using weather data at 10.00 p.m has shown in Figure 11 and Figure 12 It was found that at a radius of less than 10 meters it can produce radiant heat of more than 10 kW/m^2 which is dangerous for motorists around the location of the LNG spill. Meanwhile, at a distance of 17 meters, it only causes injuries to nearby drivers with a radiant heat of 2 kW/m^2. So it can be concluded that the safe distance (exclusion zone) in the event of an LNG spill is more than 28 meters.

Steam Cloud

If around the LNG spill there is no source fire Then a vapor cloud can form, so that LNG which has a boiling point below the ambient air temperature can evaporate quickly. If there is a source fire Around the spill, the vapor cloud can cause flash fire because the vapor cloud concentration formed can have a Lower Explosive Limit (LEL) and Lower Flammable Limit (LFL) concentration.

The steam cloud scenario simulation in the first LNG spill was carried out using weather data at 8:00 a.m so that the results as shown in Figure 13 and the coverage of the affected area can be seen in Figure 14 .

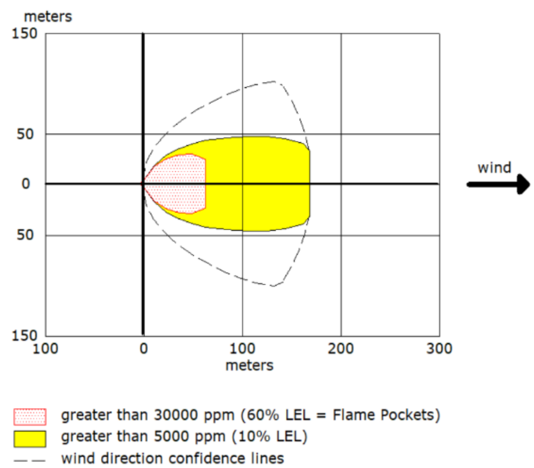

Figure 13 . Steam cloud simulation on LNG spill at 8:00 a.m

From the simulation results carried out using weather data at 8:00 a.m, the hazard zone at the LNG concentration reaches 60% LEL is at a radius of 63 meters and for 10% LEL at radius 169 meters.

Figure 14 . Mapping of the location affected by the LNG spill at 8:00 a.m on the vapor cloud review

In the weather data at 2.00 p.m, a simulation is also carried out to determine the hot steam generated from the LNG spill from the transport truck so that the simulation results are obtained as shown in Figure 15 and Figure 16 .

From the simulation results carried out using weather data at 2:00 p.m, the hazard zone at the LNG concentration reaches 60% LEL is at a radius of 57 meters and for 10% LEL at radius 160 meters.

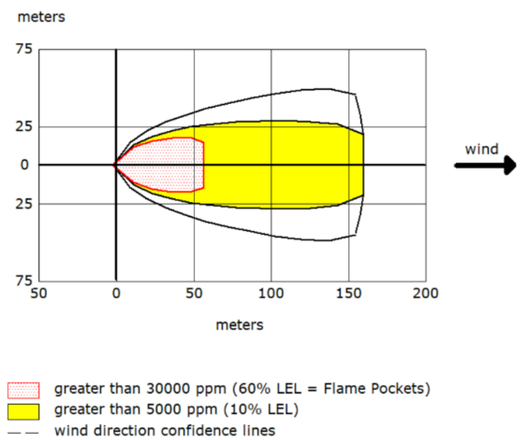

Figure 15 . Vapor cloud simulation on LNG spill at 2:00 p.m

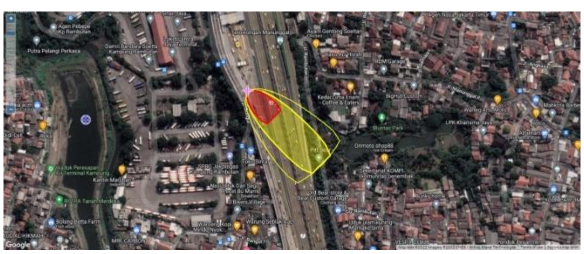

Figure 16 . Mapping of the locations affected by the LNG spill at 2.00 p.m on the vapor cloud review

The simulation of determining the hot steam scenario for weather data at 10.00 p.m WIB shows that hot steam can be formed from an LNG spill that produces radiant heat as shown in Figure 17 and the coverage of the affected area from the point where the incident occurred as shown in Figure 18 .

Base on the simulation results carried out using weather data at 10:00 p.m, the hazard zone at the LNG concentration reaches 60% LEL at a radius of 103 meters and 10% LEL at a radius of 243 meters.

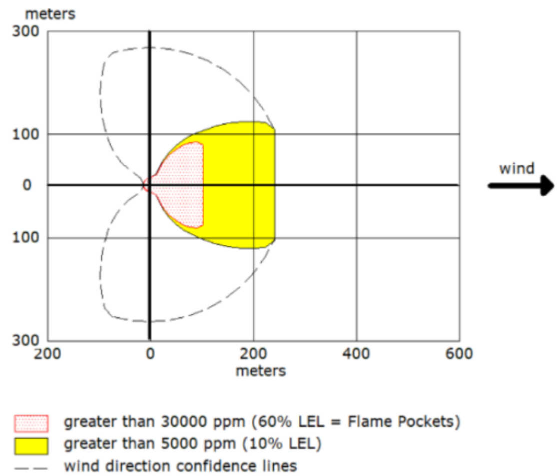

Figure 17. Vapor cloud simulation on LNG spill at 10.00 p.m

Figure 18. Mapping of locations affected by the LNG spill at 10.00 p.m on the steam cloud review.

Conclusion

Based on the simulation that has been done, fireball simulation results were obtained at 8:00 a.m, 2:00 p.m, and 10:00 p.m, are safe distances more than 812 meters, 812 meters, and 815 meters. Fire column simulation results at 8:00 a.m, 2:00 p.m, and 10:00 p.m are safe distances more than 29 meters, 29 meters and 28 meters. Steam cloud simulation results at 8:00 a.m, 2:00 p.m, and 10:00 p.m have Lower Explosive

Limits (LEL) at 169 meters, 160 meters, and 243 meters. Thus the ALOHA application can represent the results of potential safe distance scenarios in the Liquid Natural Gas (LNG) distribution process when gas is released in the distribution process.

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References

AIChe/CCPS. (2010). *Guidelines for Chemical Trasportation Risk Analysis.* New York: Center for Chemical Process Safety of The American Institute of Chemical engineers.

Aryanto, R., Tuheteru, E.J., Yulia, P.S. & Patian, S. (2021). Knowledge Sharing of Occupational Health and Safety in Mining at PT. Pilar Artha Sejahtera, Lampung. *Journal of Community Based Environmental Engineering and Management*, 5(2): 117-124

Bhattacharya, R. & Kumar, V.G. (2015). Consequence analysis for simulation of hazardous chemicals release using ALOHA software. *International Journal of ChemTech Research*, 8(4): 2038-2046.

BP. (2020). Statisyical Review of World Energy 2020 69th Edition. UK.

BP Process Safety Series. (2007). *LNG Fire Protection and Emergency Response.* London: British Petroleum.

Dinas Tenaga Kerja Transmigrasi dan Energi. (2020, November 23). *Data Stasiun Pengisian Bahan Bakar Gas (SPBG) dan Mobile Refueling Unit (MRU) di Provinsi DKI Jakarta 2020*. Diambil kembali dari Jakarta Open Data: https://data.jakarta.go.id/dataset/data-spbg-dan-mru-di-provinsi-dki-jakarta

Hanna, S. R., Briggs, G. A., & Jr, R. P. (1982). *Handbook on atmospheric diffusion: prepared for the Office of Health and Environmental Research, Office of Energy Research, U.S. Department of Energy*. United States: Dept. of Energy. Office of Energy Research., and United States. Dept. of Energy. Office of Health and Environmental Research. Technical Information Center.

Herdzik, J. (2011). LNG As a Marine Fuel-Possibilities and Problem. *Journal of KONES Powertrain and Transport*, 18(2): 169-176.

Kumar, S., H, T. T., Choi, W., & Lim, J. H. (2011). LNG: An eco-friendly cryogenic fuel for sustainable development. *Applied Energy*, 88: 4264-4273.

Maxwell, T. T., & Jones, C. J. (1995). *Conversion of Compression Ignition Engine dalam Alternative fuel: Emissions, Economics and Performance.* Pennsylvania: Society of Automotive Engineers, Inc., Warrendale.

NFPA 59A. (2013). *Standard for Production, Storage, and Handling of Liquified Natural Gas (LNG).* USA: National Fire Protection Association.

Shao, H., & Duan, G. (2012). Risk Quantitive Calculation and ALOHA Simulation in Leak Accident of Natural Gas Power Plant, *Procedia Engineering* 45, 532-359.

Yang, R., Gai, K., Yang, F., Zhang, G., Sun, N., Feng, B. & Zhu, S. (2019). Simulation Analysis of Propylene Storage Tank Leakage Based on ALOHA Software. *IOP Conference Series: Earth and Environmental Science*, 267: 042038.