Analysis of the Impact of Fire on Oil Storage Tanks at PT X: ALOHA Model Approach for Vapor Cloud Explosion Modeling

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ABSTRACT

This research aims to re-evaluate the potential hazards threatening the safety of workers and communities in the environment of the fuel oil terminal, focusing on the pertalite product tank 53 as a case study. ALOHA modeling is employed, with variables including wind speed and atmospheric stability. The methodology involves ALOHA modeling with consideration of fuel oil type, wind speed, and direction. The farthest threat zone is identified within the yellow zone, extending up to 975 meters for toxic areas and 148 meters for flammable areas, potentially impacting the Surabaya Integrated Terminal area. The potential hazards are classified as High Risk, capable of causing multiple fatalities if the worst-case scenario materializes in storage tank no. 53 with Pertalite products. Wind speed influences dispersion distance; higher wind speeds result in decreased contaminant concentration. Similarly, atmospheric stability plays a role in dispersion distance; less stability leads to better dispersion of contaminants.

Keywords: Fuel Oil Terminal, ALOHA, Vapor Cloud Explosion Modeling

1. Introduction

Occupational safety and health, commonly referred to as OSH, is a science aimed at preventing occupational accidents, occupational diseases, fires, explosions, and environmental pollution. Law No. 1 of 1970 concerning Occupational Safety clearly regulates the implementation of OSH in all workplaces where there are workers, work relationships, or business activities, as well as sources of danger, both on land, in the ground, on the surface of the water, in the water, and in the air within the territory of Indonesia[1].

Indonesia has potential oil reserves of 3.666,91 million stock tank barrels (MMSTB), while proven oil reserves amount to 3.741,33 MMSTB. In 2015, Indonesia consumed 38,5% of its fuel oil. The oil industry poses a high risk of fire and explosion hazards, often classified as "major hazards." An incident in the USA on August 6, 2012, involved a potential explosion at an oil reservoir due to a pipe rupture, resulting in minor burns for six workers. Statistics from 2012 to 2016 indicate 17 reported work accidents in oil and gas drilling areas with an Incident Rate of 0.8 per 100 workers[2]. Fires and explosions generate large plumes of smoke, small particles, and black smoke, which can affect the surrounding area. Following one such incident, local health facilities received over 15.000 residents seeking treatment for oil and gas-related illnesses.

In today's context, ensuring a safe environment and industry is crucial for the general public, professionals, and industry players alike. Additionally, the proximity of industrial units to population centers has amplified the economic and social impact of accidents. Even the best industrial units in developed countries are not immune to accidents, despite implementing safety regulations and developing methods to identify and assess hazards. Consequently, occupational accidents are considered the third leading cause of death globally.

In the large-scale industry of the mining sector, there is a high risk, for example, in the oil and gas industry and the earth industry. The numerous accidents that occur in the oil and gas industry, such as fires, explosions, environmental pollution, and others, cause the oil and gas industry to have a high potential for hazardous events against work accidents[3]. Hazards or hazards are sources that have the potential to cause losses, whether in the form of harm to humans, disease, damage to properties, the environment, or a combination of these (Frank Bird-Loss Control Management).

Notable incidents include the explosion and fire at Caribbean Petroleum Corporation (CAPECO) in 2009, resulting in the burning of 17 out of 48 petroleum storage tanks and the destruction of 300 homes and business facilities located 1,25 miles away from the scene. Similarly, a fire at Hertfordshire Oil Storage Ltd in the UK on December 11st resulted in numerous casualties and injuries among attendees.

Storage tank accidents at fuel terminals, totaling 64 incidents, rank second in number after refineries. The most common types of accidents in the oil industry include 145 fires and 61 explosions involving storage tanks. For instance, in Greece in 1986, there were 55 cases of gasoline-type fuel storage tank accidents resulting in 5 deaths, and in Kuwait in 2002, there were 4 deaths.

Oil depot explosions and fires are not uncommon in Indonesia, resulting in injuries and fatalities. Incidents such as the explosion at Pertamina Medan's stockpile tank in 2017, a fire in PT X fuel oil storage tank area in Belawan, North Sumatra in 2016, and a fire at X fuel terminal in Padang in 2014, highlight the persistent risks. Additionally, one of the largest refineries located in Cilacap experienced four consecutive fires over three years.

The Surabaya Group Installation, established in 1930 (formerly PT STANVAC), supplies and distributes various petroleum products to 982 gas stations in the East Java area, including pertalite, pertamax, pertamax turbo, diesel, FAME, pertamina biosolar, pertamina dex, LSFO180, HSFO, and avtur/JET A-1 products. The depot also supplies avtur for Juanda Airport in Surabaya, making it the largest distributor in the East Java area, contributing 40% of Indonesia's supply. However, any fire incident at this depot could disrupt fuel distribution across Indonesia. Despite the implementation of work safety systems, oil depot explosions and fires persist, indicating a lack of attention to work safety evaluation and re-evaluation by oil companies worldwide, including those in Indonesia. This research aims to re-evaluate potential hazards threatening the safety of workers and communities in the environment of fuel oil depots, with a focus on Pertalite Product Tank 53, using ALOHA modeling. The variables to be considered include wind speed and atmospheric stability.

2. Material and Methods

This research uses ALOHA (Areal Locations of Hazardous Atmospheres) software, a disperse modeling program capable of estimating threat zones associated with hazardous chemical releases including toxic vapor clouds, flames and explosions. This model is able to predict the results of an instantaneous release of chemicals and visualize the affected area or zone on a map to better understand the situation and extent of the affected area. The model can track the trace of chemicals from the time of release to vapor clouds in the air, through flammable clouds that eventually catch fire and explode[4].

ALOHA makes many predictions to provide quick results. The predicted results have been checked against similar model predictions and field experiments conducted during the trial to ensure that the results obtained are accurate. Additionally, ALOHA requires users to have some understanding of the basic parameters related to the atmosphere. In general, the ALOHA model can provide maximum benefits due to its ease of use and emission estimation capabilities[5].

One method for conducting wind direction and speed analysis is by using the windrose method [6]. The windrose diagram or wind direction diagram is a diagram that illustrates wind direction and speed conditions at a specific location over a certain period. The windrose is also used as a guide to identify the eight cardinal directions of the wind.

After identifying the threat zone, a risk potential assessment is conducted. According to Irawan et al., risk potential assessment is done using the Australian Standard/New Zealand Standard for Risk Management (AS/NZS 4360:2004) scale [7]. Model verification is performed to ensure the model is accurate[8]. However, ALOHA is a model that simulates explosions, making verification impossible. Therefore, an approach is taken to model ALOHA using another model that solves the same type of equation[9].

RMP*Comp is a model that can be used to verify ALOHA[5]. RMP*Comp is a program that can be used to solve field analysis (worst-case and alternative scenarios). The difference between ALOHA and RMP*Comp is that RMP*Comp is designed to facilitate the identification of hazards, using common and simple calculations, whereas ALOHA is designed to provide the most accurate possible estimates of the area's size and location at risk due to the release of chemical substances[10].

3. Results and Discussions

3.1. Windrose

The data needed to create the windrose is meteorological data for 2023. The meteorological data used are wind speed and wind direction which are then plotted on the WRPLOT application. The wind direction data obtained from BMKG is presented in the form of (^{o}) degrees.
The results of the Surabaya City windrose with Perak I Meteorological Station found that the dominant wind direction is towards the East (E).

3.2. ALOHA Model Result

The comparison standard used in this study is the Lower Explosive Limit (LEL) to determine the flammable area and protective action criteria (PAC) to determine the toxic area. The LEL and PAC values used are defaults from the ALOHA application. The LEL value used is 50,000 ppm for the red threat zone, 60% LEL is 30,000 ppm for the orange threat zone, and 10% LEL is 5000 ppm for yellow threat zone. As for the PAC values used, namely PAC-3 400,000 ppm for the red threat zone, PAC-2 230,000 ppm for the orange threat zone, and PAC-1 65,000 ppm for the yellow threat zone [11].

Table I. ALOHA Comparasion Standard

Threat Zone	**Raw Standard (ppm)**	**Zone**	**Sumber**
Toxic	400,000	*Red*	ALOHA
	230,000	*Orange*	ALOHA
	65,000	*Yellow*	ALOHA
Flammable	50,000	*Red*	ALOHA
	30,000	*Orange*	ALOHA
	5,000	*Yellow*	ALOHA

The results of the scenarios analyzed in this study consist of 12 tank source scenarios with the variables used are wind speed and atmospheric stability. The ALOHA scenario aims to determine the effect of wind speed and atmospheric stability on the spread distance of the threat zone. The following is a description of each variable used.

3.3. **Wind Speed**

The data used is an average of the data obtained from January 1 to December 31st, 2023. Then the meteorological data used can be seen in table 2.

Table 2. Meteorogical Data Used

Data	**Value**	**Unit**
Maximum wind speed	6.14	m/s
Average wind speed	2.14	m/s
Average temperature	28.97	^{o}C
Average air humidity	72.35	%
Cardinal Direction	East	-

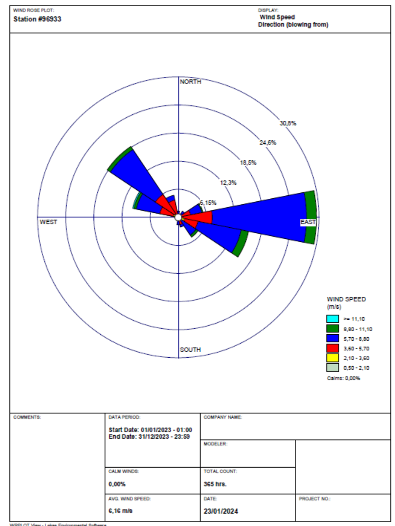

Figure 1: Wind Speed Direction WRPLOT

3.4. Atmospheric Stability

The atmospheric stability used is atmospheric stability B describes sunny conditions (tends to be unstable), D describes cloudy conditions (neutral), and F describes stable conditions. The scenario used in this study can be seen in table 3.

Table 3. Tank Source Scenario

Source	**Threat Zone**	**Speed of Wind**	**Stability of the Atmosphere**		
			B	**D**	**F**
Tank	*Toxic area of Vapor Cloud*	6.14	T.1	T.2	T.3
		2.14	T.4	T.5	T.6
	Flammable Area of Vapor Cloud	6.14	T.7	T.8	T.9
		2.14	T.10	T.11	T.12

The results of the scenario simulation on the tank source obtained by the threat zone with the Gaussian run model for the toxic threat zone and the Gaussian run model for the Flammable Area of Vapor Cloud[12] can be seen in tables 4 and 5.

Table 4. Result of Toxic Area Dispersion Analysis at Tank Source

The scenario	Category of *Threat Zone* (m)		
	Red	Orange	Yellow
1	24	70	536
2	24	69	533
3	23	66	526
4	69	179	941
5	68	177	935
6	74	188	975

Table 5. Result of Flammable Area Dispersion Analysis at Tank Source

The scenario	Category of *Threat Zone* (m)		
	Red	Orange	Yellow
7	25		62
8	25		62
9	25		61
10	46		141
11	46		140
12	49		148

3.5. Discussion
The results of the scenario simulation on the tank source which can be seen in table 4 and table 5 show that the farthest radius toxic area occurs in scenario 6 and the farthest radius flammable area occurs in scenario 12.
Simulation of scenario 6 is as follows:

1. Model Run: Heavy Gas.
2. Red Zone, with a distribution distance of 74 meters from the ignition source with a toxic vapor cloud concentration of 4,000 ppm = AEGL-3 [60 min].
3. Orange Zone, with a distribution distance of 188 meters from the leak source with a toxic vapor cloud of 800 ppm = AEGL-2 [60 min].
4. Yellow Zone, with a distribution distance of 976 meters from the leak source with a toxic vapor cloud of 52 ppm = AEGL-1 [60 min].

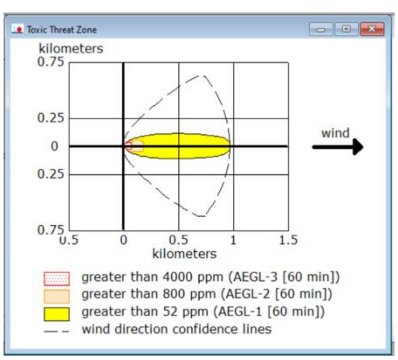

Figure 2: Scenario Model 6

The simulation of scenario 12 is as follows:

1. Model Run: Heavy Gas.
2. Red Zone, with a distribution distance of 51 meters from the leak source with a flammable vapor cloud concentration of 7,200 ppm = 60% LEL which forms Flame Pockets.
3. Yellow Zone, with a distribution distance of 149 meters from the leak source with a flammable vapor cloud concentration of 1,200 ppm = 10% LEL

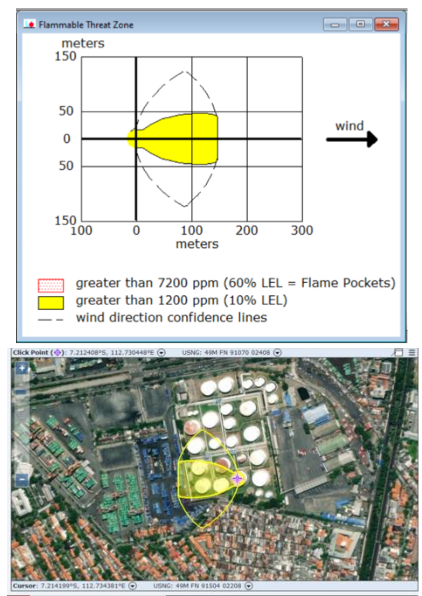

Figure 3: Skenario Model 12

In addition, the ALOHA simulation results show that the smaller the wind speed, the greater the spread distance, while the more stable the atmospheric stability, the greater the spread distance. The distance between the source of danger and residential areas and other institutions is about 45 meters. When viewed from the simulation results and the distance of the hazard source to residential areas and other institutions, the dispersal distance in scenario 6 is the worst case of the existing scenarios.

Wind speed affects dispersion distance because the greater the wind speed, the less the concentration of contaminants. Atmospheric stability also affects dispersion distance because the more unstable the stability of an atmosphere, the better the contaminants will be dispersed. This is due to the vertical movement in unstable atmospheric stability. Unstable atmospheric stability occurs because strong solar intensity causes the temperature at the earth's surface to be warmer than the air layer above it. The difference in temperature at the earth's surface with the air layer above it causes vertical air movement or vertical movement.

3.6. ALOHA Model Approach

The scenarios that will be used for this model approach consist of 5 scenarios with the emission source being direct source. The meteorological data used will be equalized with RMP*Comp because in RMP*Comp the meteorological data has been assumed.

Table 6. Scenario of ALOHA Model Approach

The scenario	Direct Source (pounds)	Speed of Wind (m/s)	Stability
1	250	1.5	F
2	500	1.5	F
3	750	1.5	F
4	1,000	1.5	F
5	1,250	1.5	F

Table 7. Simulation Results Using RMP*Comp and ALOHA

The scenario	Direct Source (pounds)	RMP*Comp (m)	ALOHA
1	250	80	89
2	500	110	128
3	750	120	159
4	1,000	130	185
5	1,250	140	208

Example of calculating the correlation value with equation 1 in scenario 1:
RMP*Comp simulation result (o) = 80 m
ALOHA simulation result (c) = 89 m
Average value of RMP*Comp ($\underline{o}$) = 116 m
Average ALOHA value ($\underline{c}$) = 153.8 m
$(c_i - \overline{c})$ = 80 – 116 = -36
$(o_i - \overline{o})$ = 89 – 153.8 = -64.8
$(c_i - \overline{c})^2$ = (80 - 116)^2 = 2,332.8
$(o_i - \overline{o})^2$ = (89 – 153.8)^2 = 1,296

Table 8. Result of Correlation Value Calculation

The scenario	c	o	$(c_i - \underline{c})$	$(o_i - \underline{o})$	$(c_i - \underline{c})$x $(o_i - \underline{o})$	$(c_i - \underline{c})^2$	$(o_i - \underline{o})^2$
1	80	89	-36	-64.8	2,332.8	1,296	4,199.04
2	110	128	-6	-25.8	154.8	36	665.64
3	120	159	4	5.2	20.8	16	27.04
4	130	185	14	31.2	436.8	196	973.44
5	140	208	24	54.2	1,300.8	576	2,937.64
Rata-rata	116	153.8					
Total					4,246	2,120	8,802.8

Then using Equation 1:

$$C_{orr} = \frac{\sum_{i=1}^{n} x\,(c_i - \underline{c})(o_i - \underline{o})}{\sqrt{\sum_{i=1}^{n} x\,(c_i - \underline{c})^2}\,\sqrt{\sum_{i=1}^{n} x\,(o_i - \underline{o})^2}}$$

$$C_{orr} = \frac{4.246}{\sqrt{2{,}120}\,\sqrt{8{,}802.8}} = 0.982882589$$

The correlation value between the ALOHA model and RMP*Comp is 0,982882589. Based on the US EPA recommendation, the correlation value between the two models is 0,572. Therefore, the model is considered correct because the correlation value meets the US EPA recommendation[10].

4. Conclusion

The farthest threat zone occurs in the yellow zone that occurs at the tank source along 975 meters for toxic areas and 148 meters for flammable areas that may occur in the Surabaya Integrated Terminal area. The potential hazards that occur are classified as High Risk which can cause multiple fatalities if the worst case occurs in storage tank no 53 with pertalite products. Wind speed affects the dispersion distance because the greater the wind speed, the concentration of contaminants will decrease. Atmospheric stability also affects the dispersion distance because the more unstable the stability of an atmosphere, the better the contaminants will be dispersed.

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