



Ethylene Evaporation Rate Analysis in the Storage Tank and Boil-Off Gas Dispersion: Case Study in PT. Lotte Chemical Titan Nusantara



Khoir Lazuardi^a, Ajeng Nina Rizky^a, Rijaalul Mulhim Al-Mauhub^b, Ibnu Faridsyah^b, Bagus Cahyadi^{c, d}, Orchidea Rachmaniah^{e*}

^aPT Losaka Energi Nusantara (LEN), Kantor CHR, Menara Grand Slipi, Lantai 9 unit O, Jl. Jend. S. Parman Kav 22-24, Palmerah, Jakarta Barat, 11480, Indonesia

^bChemical Engineering Department, Faculty of Industrial Technology and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60115, Indonesia

^cPT Lotte Titan Nusantara (LCTN), Jl. Raya Merak Km. 116, Rawa Arum, Gerem, Cilegon, Banten 42436, Indonesia

^dPT Nusantara Regas, Wisma Nusantara, Jl. M. H. Thamrin No. 59 Lantai 19, Gondangdia, Menteng, Jakarta Pusat, Daerah Khusus Ibukota Jakarta 10350, Indonesia

^eFood Engineering Programme, Chemical Engineering Departement, Faculty of Industrial Technology and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60115, Indonesia

Corresponding author : orchidea@chem-eng.its.ac.id

Abstract

As a primary raw material at PT Lotte Chemical Titan Nusantara (LCTN), ethylene storage is 12,000 tons in icy conditions (-103.6 °C and 40-80 mbarg) before processing into polyethylene. Ethylene evaporation is inevitable. Therefore, the proper handled of ethylene needs to be settled. The evaporation rate or Boil-Off Rate (BOR) of ethylene is predicted to be 0.0705-0.0730% vol/day, and the Boil-Off Gas (BOG) is 9.41-9.76 tons per day (at 21-40 °C and a tank liquid level of 15.41 meters, approx. 52.51% volume of tank). The BOR is a predicted value of the percentage of volume evaporated daily. When the liquid level is increased, the BOR rate will also be increased. The size of any leaks dramatically impacts the gas dispersion radius. A leak with a 10 mm size at wind speeds of 5 and 10 km/hr resulted in the radius distance of BOG dispersion being 8.2 and 7.7 m, respectively. When the leak hole is ten times bigger, ca. 100 mm, the radius is eight times wider. Fortunately, gas releases happen well above ground level (15.5 meters), causing the cloud to rise, keeping personnel safe. Too low liquid levels ramp up evaporation, risking shortages, while overfilling increases BOG, raising the chance of spills and safety hazards. Hence, managing these variables is crucial to keep operations smooth and safe.

Keywords: BOG; BOR; Ethylene; Evaporation rate; Storage tank

1. Introduction

Ethylene or ethane (C₂H₄) is the primary raw material used in PT. Lotte Chemical Titan Nusantara (LCTN) will produce polyethylene (PET). PT. Lotte Chemical Titan Nusantara is Indonesia's biggest polyethylene producer, mainly of high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE). Hence, ethylene storage is essential for the continuity of polyethylene formation at PT. Lotte Chemical Titan Nusantara. The ethylene storage tank is responsible for storing 12,000 tons of ethylene liquid phase from the jetty at -103.6°C and 40-80 mbarg before flowing to the primary process.

Ethylene is a gas (at room temperature) that is highly flammable, non-corrosive, and colorless, and it has a sweet aroma and taste. Figure 1 shows the pictogram mark for ethylene, which means that ethylene is dangerous. GHS classification for ethylene is flammable gas: category 1A; gas under pressure: compressed gas; specific target organ toxicity, single exposure; respiratory tract irritation: category 3; specific target organ toxicity, single exposure; narcotic effects: category 3. Direct exposure to Ethylene can cause feelings of drowsiness and dizziness.



Figure 1. Pictogram Mark for Ethylene

Based on the Safety Data Sheet (SDS), Ethylene has a molecular weight of 28.05 g/mol, 1.138 kg/m³ (at 25°C, gas phase). In contrast, as a liquid phase, ethylene has physical properties such as a density of 570 kg/m³ (at -104°C), a melting point of -169°C (at 1 bar), a boiling point of -104°C (at 1 bar), a critical temperature of 9.2°C, and a critical pressure of 50.42 bar. Due to its low melting and boiling points, a small portion of the ethylene liquid will evaporate into the gas phase during storage. This phenomenon is referred to as Boil-Off Gas (BOG). Moreover, the autoignition temperature of ethylene is 450°C, the flash point is -136 °C, and the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) are 2.75% and 28.6%, respectively. Therefore, a special precaution is needed to store Ethylene. It should be stored in a closed, low-temperature space and kept away from sources of fire, such as open flames, flares, cigarette fires, and others. In addition, Ethylene stored in large capacity is safely stored in its liquid phase with temperatures below -103 °C instead of being stored in the gas phase due to the required space volume for ethylene liquid storage being 500-600 times smaller than its gas phase storage.

In the case of PT LCTN, Ethylene is their primary raw material, with 12,000 tons stored in a wall cylinder tank and a cryogenic tank type. It is covered by five layers: 120 mm insulation fiberglass blankets, 719 mm layer of loose perlite, 50 mm thick insulation spray glass blankets, 50 mm sprayed polyurethane foam insulation, and a 6 mm outer shell plate, while the inner shell plate itself has a 5 mm shell thickness. The inner and outer shell plates are made from 9%-nickel alloy steel with ASTM A553M material code. The tank insulations are designed to avoid an increase in the ethylene liquid due to heat loss by the difference between the liquid and ambient temperature. In addition, the top of the storage tank is insulated with fiberglass, while the bottom is insulated with dry sand and foam glass HLB115.

The tank is also equipped with a BOG system, which maintains the temperature and pressure of the storage system. This system directly maintains the phase of liquid Ethylene since the BOG phenomenon is unavoidable and must be removed immediately from the tank to avoid the endangered effects. BOG may happen due to the heat flow from the environmental air through the tank insulation, causing compositional changes in the tank, increasing pressure, and adversely affecting the material tank's stability and safety. In the BOG system, ethylene vapor at the top of the tank is sucked into the reliquefied compressor and reliquefied. At the liquefier, the ethylene vapor temperature is cooled from 45°C to -35°C. Finally, the ethylene vapor returns to the liquid phase, which is returned to the storage tank. The ethylene vapor in the tanks is reduced, reducing the effects that BOG can cause. The presence of BOG can be predicted by calculating the evaporation rate of Ethylene or boil-off rate (BOR). Therefore, phase changes of Ethylene are critical. Maintaining the temperature and pressure of ethylene storage is of urgent importance. Hence, the relationship between ambient temperature and the Ethylene or BOR evaporation rate and ethylene level is analyzed to avoid overpressure in the ethylene storage tank. Based on several existing control factors, the resulting relationship will recommend the safe zone.

Meanwhile, toxic ethylene gas needs to be checked for the gas spread radius if BOG combustion fails in the flare. Knowing the range of the gas spread radius allows the company to know the area with potentially dangerous gas concentrations, thus allowing the company to prepare preventive and mitigative steps to prevent fire hazards that can cause equipment damage, potential injury or fatality to personnel, and environmental pollution (air pollution).

2. Method

2.1 Boil-Off Rate (BOR) and Boil-Off Gas (BOG) Calculation

The evaporation rate or boil-off rate (BOR) is the percentage of volume evaporated daily. This BOR is predicted using an equation where the total heat energy is divided by the amount of latent heat of vaporization, volume, and the density of Ethylene in the tank, such as equation (1):

$$BOR = \frac{Q \times 24 \times 3600}{\Delta h \times V_{eth} \times \rho} \times 100\% \quad (1)$$

With BOR as %vol/day, Q is total heat transfer [W], Δh is the latent heat of vaporization [kJ/kg], V_{eth} is the volume of Ethylene in the tank, and ρ is density [kg/m³].

Meanwhile, Q is the tank heat transfer caused by the temperature difference between the liquid and the environment. Heat transfer covers heat transfer from convection, radiation, or conduction. Heat convection comes from heat transfer by mass motion of fluids such as environmental air and ethylene liquid in the tank. Heat radiation generally comes from the heat of sunlight; since ethylene storage tanks are usually coated with white anti-radiation paint, this part is ignored in the calculation, and the last is heat conduction, which is the heat transfer through the layers of the tank wall. This type of heat occurs from any side of the storage tank. Thus, the calculation of heat transfer is calculated using equation (2):

$$Q = Q_w + Q_t + Q_b \quad (2)$$

Q_w is the heat transfer from the liquid and storage tank; the calculation follows equation (3). Since the Q_w is a combination of heat transfer by convection of liquid fluid and conduction of the layer of the tank wall, the equation (3) follows:

$$Q_w = \frac{-2\pi \times H_{eth} \times (T_{eth} - T_{out})}{\frac{1}{r_i \times \alpha_{in}} + \sum \left(\frac{1}{k_n} \times \ln \left(\frac{r_n}{r_{n-1}} \right) \right) + \frac{1}{r_n \times \alpha_{out}}} \quad (3)$$

Where H_{eth} is liquid height [m], T_{eth} is liquid temperature [K], T_{out} is the temperature of the outer environment of the tank [K], r is the layer radius from the center of the tank [m], k is the thermal conductivity [W/m.K], and α_{in} and α_{out} are convection heat transfer coefficients [W/m².K].

In the case of an ethylene storage tank at PT Lotte Chemical Titan Nusantara (PT LCTN), heat transfer through the tank wall (Q_w) includes all the insulation lining walls, i.e., the surrounding walls (wall), the roof (top), and the bottom of the tank (bottom).

Heat throughout the tank wall comes from air convection at ambient temperature and conduction through the tank layer insulations. They are 5 and 6 mm thick for the inner and outer surfaces of shell wall plates, respectively, 120 mm for the fiberglass blankets, 719 mm for the perlite, and 50 mm for the polyurethane foam. At the same time, heat conduction occurs from outside, such as environmental air and the fluid itself, Ethylene. The variety of fluid height and ambient temperature of the tank influences the value of heat conduction. Therefore, the heat transfer from the liquid and storage tank (Q_w) equation (3) expanded as follows, equation (4):

$$Q_w = \frac{-2\pi \times H_{eth} \times (T_{eth} - T_{out})}{\frac{1}{r_i \times \alpha_{in}} + \frac{1}{k_{1,w}} \times \ln \left(\frac{r_{1,w}}{r_i} \right) + \frac{1}{k_{2,w}} \times \ln \left(\frac{r_{2,w}}{r_{1,w}} \right) + \frac{1}{k_{3,w}} \times \ln \left(\frac{r_{3,w}}{r_{2,w}} \right) + \frac{1}{k_{4,w}} \times \ln \left(\frac{r_{4,w}}{r_{3,w}} \right) + \frac{1}{k_{5,w}} \times \ln \left(\frac{r_{5,w}}{r_{4,w}} \right) + \frac{1}{r_s \times \alpha_{out}}} \quad (4)$$

Q_t is the heat transfer from the top/roof of the tank. Q_t combines heat transfer by convection and conduction at the top of the storage tank. Ethylene storage tanks are usually spherical domes, with the inside of the roof/top of the cylinder covered with a flat insulation plate. Thus, the calculation of Q_t is quite complex. Instead of calculating according to its shape, a simplifying value is assumed to be approximately 40-50 kW [1]. Moreover, Q_b is the heat transfer from the bottom of the tank, and the calculation follows equation (4). It combines convection and conduction heat transfer at the bottom of the tank. Convection occurs in the liquid of the tank, while conduction occurs through the layers of the bottom wall of the tank as well as conduction from the soil—The bottom wall of the tank and conduction from the ground. However, if the tank is not directly in contact with the ground and uses piles to support the tank, then conduction by the ground is replaced by convection by environmental air. Hence, Q_b can be calculated following equation (5):

$$Q_b = \frac{-\pi \times r^2 \times (T_{eth} - T_s)}{\frac{1}{\alpha_{in}} + \sum \left(\frac{s_n}{k_n} \right) + \frac{1}{\alpha_s}} \quad (5)$$

With r is the inner radius of the storage liquid [m], T_s is the bottom surface temperature of the tank [K], s is the layer thickness [m], and α_s is the outer convection heat transfer coefficient under the tank [W/m².K]. For example, Q_w , the heat transfer at the bottom, also counts the heat convection from the outside air of the tank, the ethylene fluid, and the heat conduction from the six layers of the tank's insulations. Therefore, equation (5) becomes equation (6):

$$Q_b = \frac{-\pi \times r^2 \times (T_{eth} - T_s)}{\frac{1}{\alpha_{in}} + \frac{s_{1,b}}{k_{1,b}} + \frac{s_{2,b}}{k_{2,b}} + \frac{s_{3,b}}{k_{3,b}} + \frac{s_{4,b}}{k_{4,b}} + \frac{s_{5,b}}{k_{5,b}} + \frac{s_{6,b}}{k_{6,b}} + \frac{1}{\alpha_s}} \quad (6)$$

Moreover, all the parameters' values from the engineering data used in the calculations are in Table 1.

Table 1. Parameters Values For The Calculation Boil-Off Rate (BOR)

Parameters (symbols, units)	Values
Latent Heat of Vaporization Ethylene (Δh , J/kg)	483,000
Area of Surface Ethylene (A_s , m ²)	1520.53
The volume of Liquid Ethylene in the Tank (V_{eth} , m ³)	23431.38
Density of Ethylene (ρ , kg/m ³)	570
Height of Ethylene Tank Filled (H_{eth} , m)	15.41
Temperature of Liquid Ethylene (T_{eth} , K)	170.15
Ambient Temperature (T_{out} , K)	303.15
Inner Tank Radius (a , m)	22
Radius to Outer of Inner Shell ($r_{1,w}$, m) ^a	22.005
Radius to Outer of Fiber Glass Blankets ($r_{2,w}$, m)	22.125
Radius to Outer of Loose Perlite Layer ($r_{3,w}$, m)	22.844
Radius to Outer of Sprayed Puf Layer ($r_{4,w}$, m)	22.894
Radius to Outer of Outer Shell ($r_{5,w}$, m) ^a	22.9
Inner Wall Convective Heat Transfer Coefficient (α_{in} , W/m ² .K)	0.25688
Outer Convective Heat Transfer Coefficient (α_{out} , W/m ² .K)	0.19825
Thermal Conductivity of Inner Shell ($k_{1,w}$, W/m.K) ^b	52
Thermal Conductivity of Fiber Glass Blankets ($k_{2,w}$, W/m.K) ^c	0.0191
Thermal Conductivity of Loose Perlite ($k_{3,w}$, W/m.K) ^d	0.04608
Thermal Conductivity of Sprayed Puf ($k_{4,w}$, W/m.K) ^e	0.023
Thermal Conductivity of Outer Shell ($k_{5,w}$, W/m.K) ^b	52
Ground Temperature (T_s , K)	303.15
Outer Ground Convective Heat Transfer Coefficient (α_s , W/m ² .K)	0.28175
Thick of Inner Bottom ($s_{1,b}$, m)	0.005
Thick of Inner Dry Sand ($s_{2,b}$, m)	0.044
Thick of Foam Glass ($s_{3,b}$, m)	0.381
Thick of Outer Dry Sand ($s_{4,b}$, m)	0.075
Thick of Outer Bottom ($s_{5,b}$, m)	0.006
Thick of Concrete Slab ($s_{6,b}$, m)	2
Thermal Conductivity of Inner Bottom ($k_{1,b}$, W/m.K) ^b	52
Thermal Conductivity of Inner Dry Sand ($k_{2,b}$, W/m.K) ^f	0.16
Thermal Conductivity of Foam Glass ($k_{3,b}$, W/m.K)	0.026
Thermal Conductivity of Outer Dry Sand ($k_{4,b}$, W/m.K) ^f	1.76
Thermal Conductivity of Outer Bottom ($k_{5,b}$, W/m.K) ^b	52
Thermal Conductivity of Concrete Slab ($k_{6,b}$, W/m.K) ^e	0.1

^aASTM, 2022; ^bMatweb, 2023.; ^cSmith, 1981; ^dPerlite Insititute, 2013; ^eKhan, 2020; ^fHamdhan, 2010

2.2 Boil-Off Gas (BOG) Dispersion Modelling

Flammable and highly volatile ethylene can represent a safety danger to personnel at the plant and a serious environmental hazard if released into the atmosphere. Dispersion modeling is used to estimate the concentration of substances transported by the wind in neutrally buoyant conditions, in which the density of the substance is the same as the density of the air, causing the substance to neither float nor sink. Gas dispersion modeling with SAFETI software version 9.0 can be used to see the effects of gas release with the hole size and wind speed variables. The model used in SAFETI is the Unified Dispersion Model (UDM). By modeling the distribution of flammable gases, this model can predict the behavior of gases influenced by wind and air entry from the atmosphere. A coordinate of 5.97°S 106.01°E is used, showing a point of the Gerem, Cilegon, Banten 42436, Indonesia.

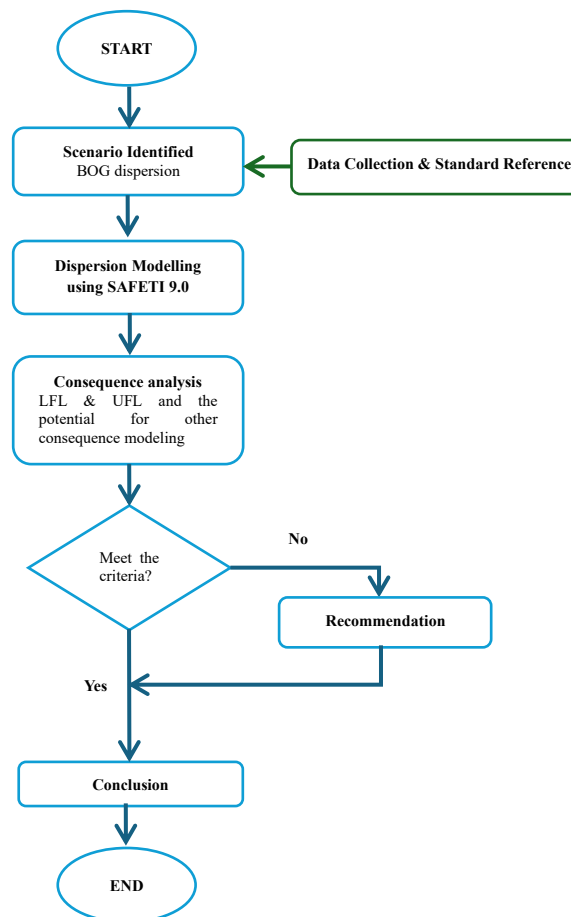


Figure 2. Flowchart of Dispersion Modeling Methodology

Table 2. Environmental Conditions on Pasquill Stability^a

Windspeed (m/s)	Daytime Insolation			Night-time conditions		Anytime
	Strong	Moderate	Slight	Thin overcast or >4/8 low cloud	3/8 cloudiness	Heavy overcast
< 2	A	A – B	B	F	F	D
2 – 3	A – B	B	C	E	F	D
3 – 4	B	B – C	C	D	E	D
4 – 6	C	C – D	D	D	D	D
> 6	C	D	D	D	D	D

^a Yellow Book;

Table 3. Hole Size and Wind Speed Variance

Assumed Hole Size	10 mm and 100 mm
Wind Speed ^a	5 km/hr and 10 km/hr
Average Humidity ^a	88%
Average Ambient Temperature ^d	303.15°K (30°C)
Environmental conditions ^c	20-80% cloud cover as partly cloudy (Pasquill Stability D)
BOG	9.58 tons/day
Height of release	15.5 m ^d

^aBMKG, 2025; ^bMeteoblue.com, 5.97°S 106.01°E.; ^cYellow Book; ^dTable 1

Table 4. Annual Average Wind Speed and Wind Directional Probability^a

Wind Direction	Wind Speed km/h					
	<2	2.0 – 5.0	5.0 – 10.0	10.0 – 20.0	20.0 – 30.0	30.0 – 40.0
North	18.8	113.0	166.8	41.4	0.1	0.0
North North-East	27.5	130.2	219.0	42.9	0.0	0.0
North East	20.2	144.8	253.5	108.3	0.2	0.0
East North-East	30.1	187.7	315.5	155.7	1.2	0.0
East	22.3	204.8	347.4	104.7	0.3	0.0
East South-East	34.0	231.2	264.5	20.4	0.0	0.0
South East	26.0	204.5	101.7	0.8	0.0	0.0
South South-East	37.2	200.7	86.2	0.1	0.0	0.0
South	28.8	181.4	124.1	3.3	0.0	0.0
South South-West	30.8	178.8	270.5	77.4	0.3	0.0
South West	20.5	147.3	356.5	584.9	17.5	0.0
West South-West	26.5	127.4	308.3	705.1	100.5	0.2
West	19.2	104.2	213.0	188.6	23.4	0.4
West North-West	27.0	105.9	161.9	46.0	0.2	0.0
North West	20.7	100.4	136.1	38.4	0.0	0.0
North North-West	27.4	111.7	156.4	59.9	0.6	0.0

^aMeteoblue.com, 5.97°S 106.01°E

The released gas from the facility will form a gas cloud dispersed by the initial momentum of the release, turbulence around the obstruction, and wind. Hydrocarbon gas cloud envelopes are determined by the Lower Flammable Limit (LFL) and Upper Flammable Limit (UFL). The extent of the hydrocarbon gas dispersion will be the basis for an explosion. When the gas cloud is ignited with turbulence, an explosion will occur. On the other hand, when the gas cloud is ignited without turbulence, a flash fire will occur.

Table 5. Flammable Dispersion Criteria

%Concentration	Dispersion Criteria
100% LFL	100% probability of death for personnel in a flammable cloud if the gas cloud is ignited without turbulence [14]
50% LFL	To initiate continuous visible and audible alarms and appropriate executive action [14]
20% LFL	To start a continuous visible and audible alarm until the gas event clears and can be reset [14]

3. Results and Discussion

Both boil-off gas (BOG) and boil-off rate (BOR) are predicted at various ambient temperatures, in the range of 21-40 °C, and may be present at the plant site PT LCTN throughout the year.

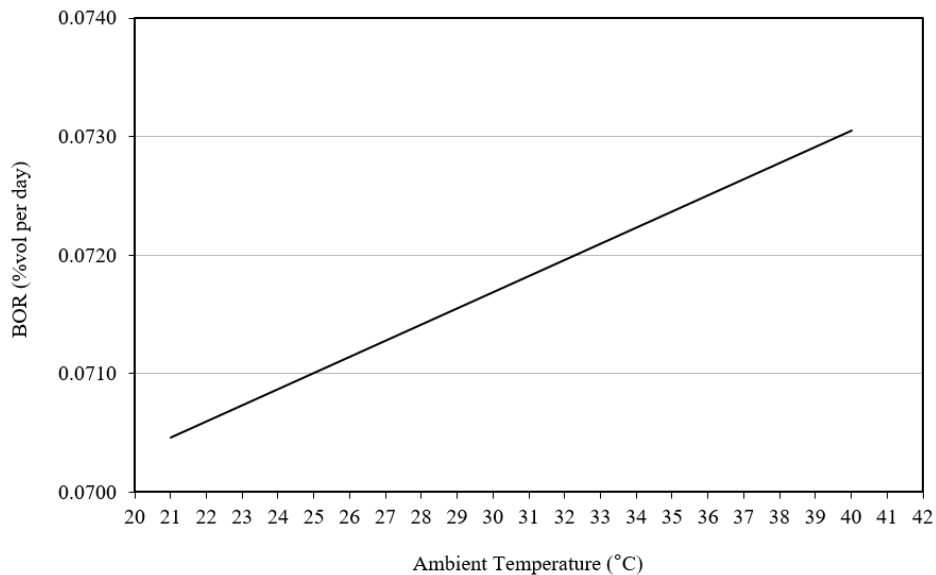


Figure 3. BOR (% Vol per Day) in variances of Ambient Temperature

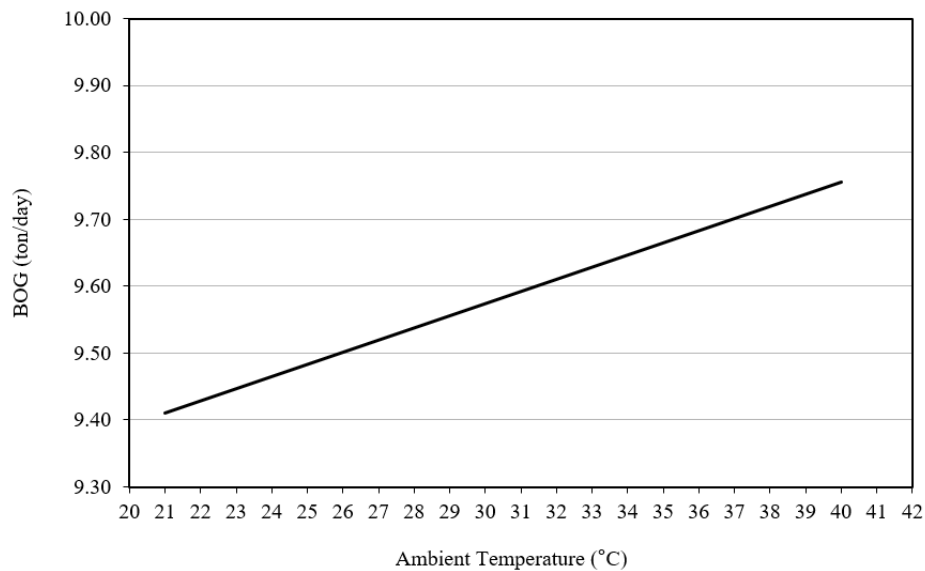


Figure 4. BOG (Ton per Day) in variances of Ambient Temperature

Figures 3 and 4 show that the ambient temperature is directly proportional to the value of BOR and BOG. The BOR rate, in the range of 21-40°C, was predicted to be 0.0705-0.0730% per day, while the BOG is expected to be 9.41-9.76 tons per day, with the ethylene liquid level in the tank is 15.41 meters (23,431.38 m³, 52.51% volume of tank) and the inner tank radius is 22 m. Unlike the other graphs, Figure 5 shows a sloping downward graph, while Figure 6 shows a straight upward graph. Those figures indicate that the effect of the height of liquid Ethylene in the tank is not directly inversely proportional to the BOR rate but directly proportional to the amount of BOG formed. In the range of liquid Ethylene in the tank of 1-17.34 meters with an ambient temperature of 30°C, the predicted BOR rate is 0.9357-0.0650%vol per day, and the amount of BOG is 8.11-9.77 tons per day.

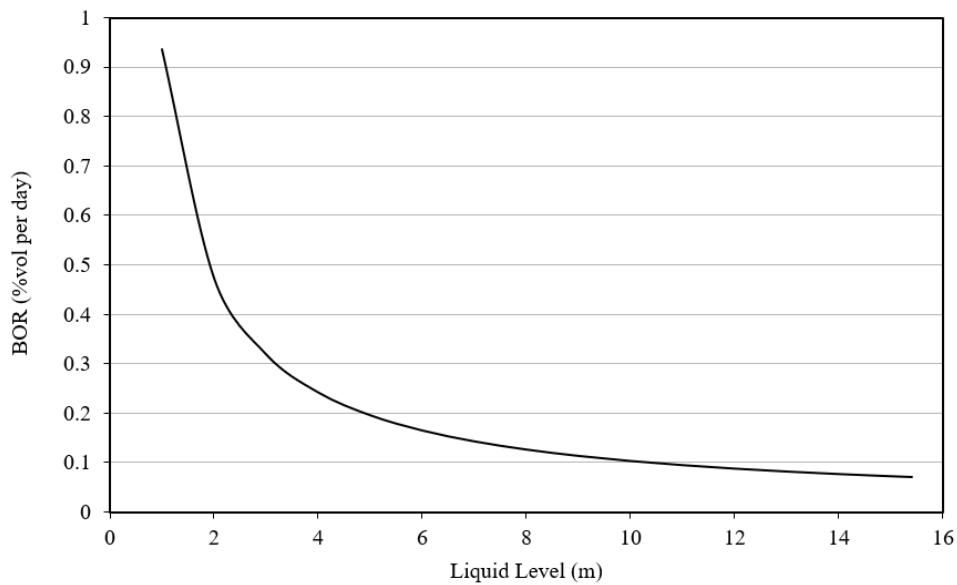


Figure 5. BOR (% Vol per Day) in variances of Ethylene Level

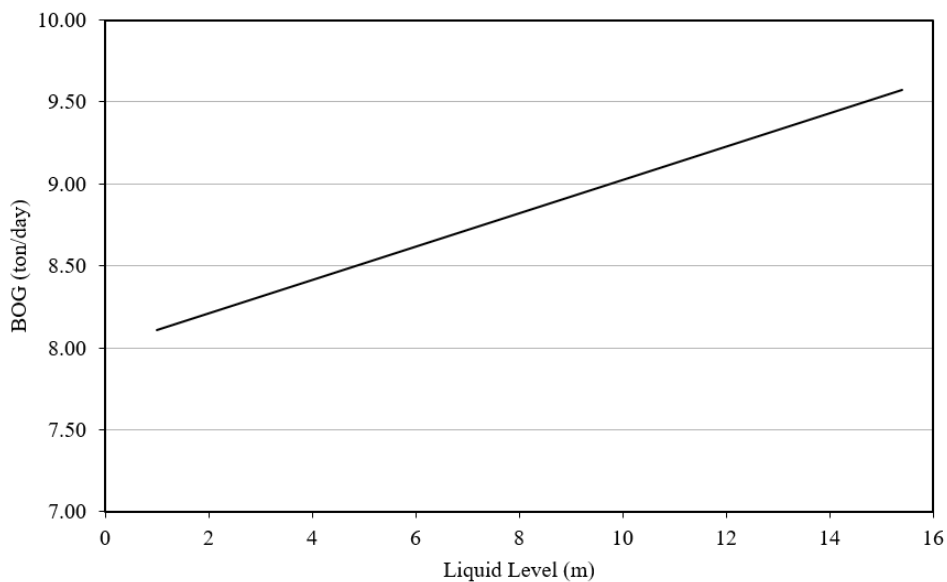


Figure 6. BOG (Ton per Day) in variances of Ethylene Level (m)

To deal with the influence of ambient temperature, the insulation and thermal defense of the tanks need to be considered. Inspection and maintenance should be carried out regularly. PT Lotte Chemical Titan Nusantara can improve thermal defense by using paint with better thermal resistance.

The height of liquid Ethylene in the tank should be kept neither too low nor too high. Liquid levels that are too low accelerate BOR and can risk a lack of materials. The low liquid level can cause the production process to stop and lead to significant losses for the company. Liquid levels that are too high increase BOG and pose a risk to safety, such as spillage or overfilling.

The radius distance of BOG dispersion in 20% LFL at a hole size of 10 mm with wind speeds of 5 km/hr and 10 km/hr is 8.2 m and 7.7 m, respectively, as shown in Figure 7. Moreover, Figure 8 demonstrates that the radius distance of BOG dispersion in 20% LFL at a hole size of 100 mm with wind speeds of 5 km/hr and 10 km/hr is 64.7 m and 56.7 m, respectively. The faster the wind, the shorter the radius of gas dispersion release. As the wind speed increases, the gas particles transported by the wind are swiftly dissolved by the wind, causing the gas concentration to thin out. Conversely, the slower the wind speed, the longer the gas transported by the wind will take a long time to dissolve, so reaching the safe limit concentration will require a longer distance than higher wind speeds [13].

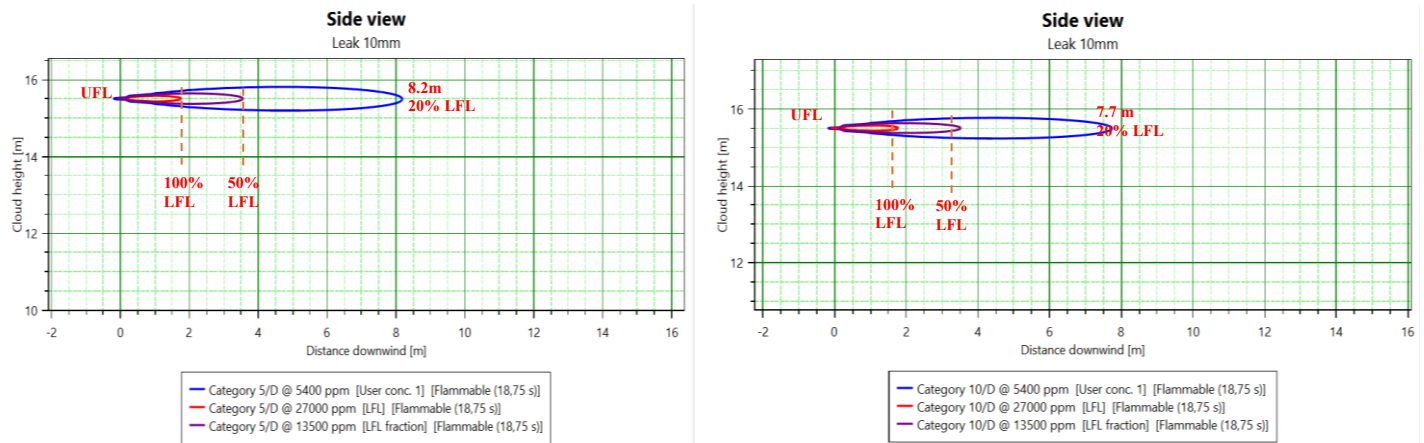


Figure 7. BOG Dispersion Result for Hole Size 10 mm (Wind Speed 5 km/hr and 10 km/hr)

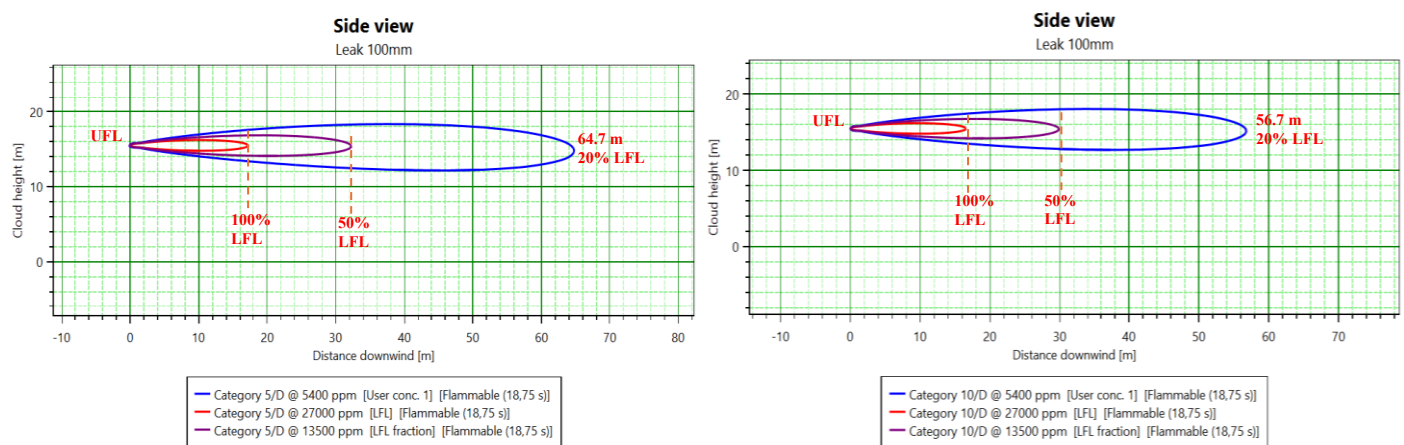


Figure 8. BOG Dispersion Result for Hole Size 100 mm (Wind Speed 5 km/hr and 10 km/hr)

Hydrocarbon release with significant potential for flashing off gas can produce an explosion. Explosions are delayed ignition events, in which they require a gas cloud to build up before igniting. Flammable gas that is dispersed has the potential to cause an explosion. When the gas cloud is ignited with turbulence, an explosion will occur. Explosions can cause equipment damage and personnel fatalities; therefore, further analysis is needed regarding the explosion modeling of the BOG dispersion.

4. Conclusions

The increase in ambient temperature causes an increase in the boil-off rate. In the 21-40°C (liquid level = 15.41 m), PT LCTN is predicted to experience a BOR of 0.705-0.730% vol per day and a BOG of 9.41-9.76 tons/day. The higher ethylene level in the tank causes a decrease in the boil-off rate. The influence of this variable has a more significant effect on BOR than the influence of ambient temperature. Ambient temperature. In the 1-17.34 m (30°C) level range, PT LCTN experienced a BOR of 0.9357- 0.0650%vol per day and BOG 8.11-9.77 tons/day. Gas dispersion results show that if the gas release occurs at a height of 15.5 meters from the ground, the personnel near the storage tank are in a safe position to work due to the flammable gas cloud continuing to expand upwards, and environmental contamination, specifically air pollution, can be reduced.

However, hydrocarbon release in UFL and LFL is a potentially delayed explosion if any ignites (e.g., lightning), and it can cause damage to equipment, injury to personnel, or fatality. Routine inspection and maintenance of flare systems and utilities, and replacement of damaged components, are required as preventive measures. If tank head maintenance is being performed, personnel must be equipped with a portable gas detector because exposure to ethylene gas can cause headaches, dizziness, weariness, vertigo, confusion, or loss of consciousness.

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