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Vessel Mooring Analysis and Ignition Range Dispersion Analysis for LNG Jetty Facilities

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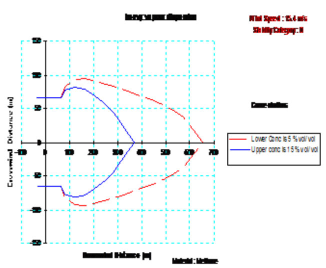
Graphical abstract


Vapor Dispersion Range Analysis

Abstract

The LNG jetty is facilities (forming part of the terminal) for the berthing and unloading of LNGC, including all shore-side discharging arms and docking facilities.The criteria design to build new LNG based on some aspect such as the result of bathymetric survey, the tanker or other vessel, port facilities, mooring layout, and also catastrophic accident such as LNG vapor dispersion. One of the critical issue on the LNG Jetty design is the configuration of mooring vessel, that should be analyzed before vessel need to berth on jetty. Mooring are provided to prevent vessel from drifting away from a berth. It is assumed that the wave motions are unaffected by the stiffness of the mooring lines and fenders.

Keywords: LNG; jetty; mooring; dispersion

1.0 INTRODUCTION

The development of new LNG facilities should be start with the proper port facilities layout to handle deep draught tanker, the vessel access and navigation channel, the mooring layout of the biggest tanker, sheltered place to limit environmental load and certified cargo safety transfer system.

Jetty location should be chosen to reduce the risk of passing ship striking berthed LNG Carrier. The acceptability of the chosen position have to considerate the sector economic, political, and social of the local area. The most recommended site selection process removes as many risk as possible by choose LNG terminal in sheltered location or remote area with adequate depth reduce the possibility collision risk.

The main purpose of this paper is to show the main aspect to be considered on LNG jetty site selection. There is special consideration if LNG will be built near existing facilities, the location should be out of the range of LNG vapor dispersion.

2.0 GENERAL SITE SELECTION CRITERIA

The site selection depends on the location of market, minimizing transportation and storage cost, reducing the risk of passing ships striking a berthed LNG carrier. The recommended locations is sheltered place remote from other port users with adequate water depth for navigation channel and also have low risk of dynamic wave forces.

The requirement on site selection port facilities such as [Ref.1]:

1. Bathymetric

The proposed jetty location should meet adequate water depth for the navigation, vessel berthing and mooring. The amount and the rate of siltation in the channel should be estimated to determine the frequency of maintenance dredging in the future. Estimation of siltation rate can be made by analyzing the record of sounding survey and mathematical sedimentation modeling methods. This information can be used as a basic to plan maintenance dredging.

The depth of navigation channel can be study with this following equation [Ref.2]:

$$H = d+G+R+P+S+K \quad (1)$$

where,

d = maximum ship draft
G = wave motion including trim and squat
R = net under keel clearance
P= sounding error
S = allowable sediment deposition between dredging operation
K = dredging error
G+ R is brute under keel clearance.

2. Environmental Condition

It is very important to know the features of the shore to determine whether the structure will be affected by environmental impact. Environmental impact such as hydrodynamic forces, wave height, wave frequency, water quality and ecology should be analyzed to determine size and direction of LNG Jetty. The type of vessel includes her dimension and speed should be investigated to ensure that vessel can berth and moored at possible wave situation. LNG facilities should install wind speed and current monitoring equipment.

3. Mooring

Hydrodynamic forces become one of the important issue on mooring vessel design. Design mooring should consider several things such as:
location and strength of mooring bollard, mooring load monitoring equipment, loading arm envelope and cut off point for ERS (Emergency Release System) operation.

4. Ignition Risk

The risk of LNG spillage should be considered as one important aspect of site selection criteria. The area free ignition risk zone can be analyzed by formation and dispersion characteristic of gas clouds under variety of weather conditions. The safety procedure was taken to limit risk of spills and reduce the probability of gas cloud ignition such as:

- Establish ignition-free offshore zones to stop entry by small craft.
- Disallow simultaneous LNG operations and ship movements at adjacent jetties
- Have available local weather forecasts with suitable warning systems
- Have pilots and tugs ready at short notice for emergency departure

5. Cargo Transfer System

The transfer system in loading platform should use loading arm system. LNG from LNG tanker to loading platform should use loading arm. The LNG jetty should set limits for cargo stoppage, hard arm disconnection and un-berthing. The system should be incorporated on loading arm include:

- Interlinking of LNG Tanker Emergency Shutdown (ESD) System on loading platform.
- Establishing the linkage for ship shore ESD control.
- Fitting PERCs and their quick acting valves.
- Linking ESD systems and PERCs into a unified control system called ERS (Emergency Release System).

3.0 STUDY CASE

The detail location of the study case show in Figure 3. The dimension of LNG jetty is calculated as a function of equipment layout and area needed for the operation. The LNG Jetty facilities consist of loading platform with dimension 27.5 mx18 m, breasting dolphin with dimension 12 mx12 m and mooring dolphin with dimension 12 mx12 m show on Figure 1.

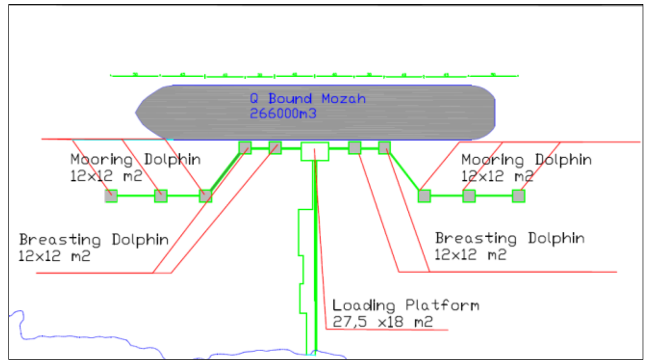


Figure 1 LNG jetty configuration

For the site selection LNG Jetty analysis will use the following environmental data on Table 1 and Table 2.

Table 1 LNG tanker characteristic

Parameter	Nominal
Tank Capacity(m3)	266.000
DWT (T)	125.700
Loa (m)	345
Lpp(m)	341.5
Breadth(m)	53.80
Depth(m)	30.50
Draft (m)	13.60
Aproaching Velocity(m/s)	0.5

Table 2 Environmental condition

Parameter	Nominal
Maximum wind speed (berthing)	10.3 m/s
Maximum wind speed (LNG transfer)	15.4 m/s
Maximum significant wave height (maneuvering)	1.5 m
Maximum significant wave height (LNG transfer)	2 m
Maximum current (maneuvering)	2.1 m/s
Maximum current (LNG transfer)	1.8 m/s
Tide	4.2 m

The analysis will include design criteria for facilities design, vapor cloud dispersion range, and mooring layout.

4.0 MOORING VESSEL ANALYSIS

Mooring are provided to prevent vessel from drifting away from a berth. It is assumed that the wave motions are unaffected by the stiffness of the mooring lines and fenders. Motions of the moored vessel in first response to waves, for example roll, sway, pitch, and heave, are independent motions but can increase peak loads on mooring lines.

Movement should be restrained by means of an adequate number of mooring lines, which can be readily handled by the operating personnel, compatible with the conditions of winds, tides, waves and other effects likely to be experienced during the period a vessel is berthed. The mooring layout is dependent on the size and type of vessel using the berth, and the position, spacing and strength of the moorings on the jetty.

Principal on mooring line configuration [Ref.4]:

- Mooring arrangements should be as symmetrical as possible about the mid-length of the ship. To ensure the distribution of the restraining forces on the vessels.
- Mooring line should not be too long to avoid movement of the vessel.
- Breast lines should be as perpendicular as possible to the longitudinal center line of the ship.
- Spring lines should be as parallel as possible to the longitudinal center line of the ship. to provide the maximum restraint against the vessel surging along the jetty.
- Head and stern lines are generally not necessary provided that mooring points are suitably designed and arranged.
- The vertical mooring angle should be as small as practicable and preferably not greater than 25º.
- For directional environment, site-specific mooring patterns may be considered to enhance lateral and/or longitudinal restraint.
- Mooring lines in the same service should have the same length with the ship's winch and the jetty mooring points and should be of the same size and material.

The selection of mooring line consider about some factor such as material, construction, corrosion protection, strength of mooring line and diameter of mooring line. Table 3 show the requirement for mooring line [Ref.4]:

Table 3 Mooring line strength criteria

Fitting	SWL	SF=MBL/SWL	%MBL	Test load
Moorin g lines	Highest load calculated for standard environmen tal criteria	Steel=1.82 Polyamide 2.22 Other Synth:2.00	55% 45% 50%	Test sample to destructio n to confirm MBL

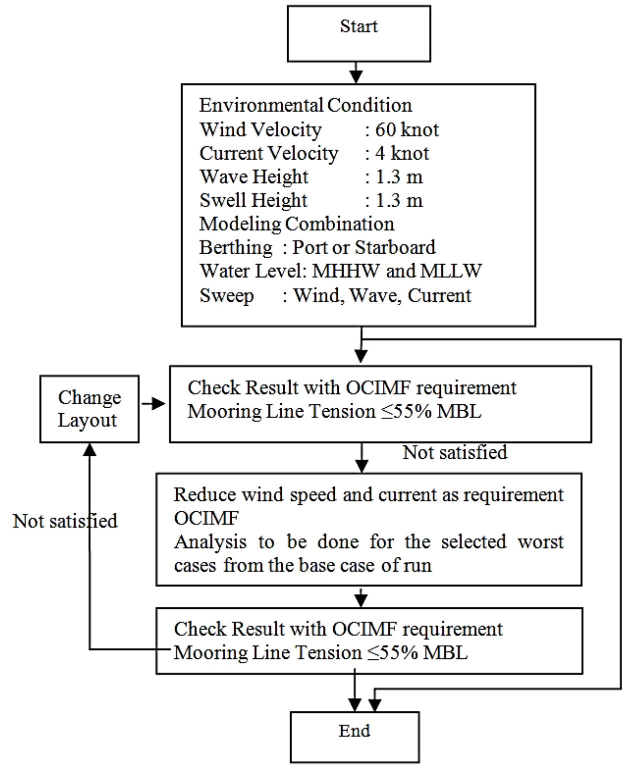


Figure 2 Mooring analysis procedure

Figure 2 show the mooring analysis procedure. It shows the stage to define the suitable configuration for vessel mooring layout. First stage, define environmental data and modeling combination on port and starboard. After modeling, run and check the result with OCIMF requirement which is mooring line tension less than 55% MBL. If the result not satisfied consider to limit access current and wind speed from the OCIMF requirement, use actual wind and current speed, run and check mooring tension, if not satisfied again, change the mooring layout, or choose suitable material properties for mooring line.

Mooring analysis should consider environmental data such as wind force. For any given wind velocity, both the transverse and longitudinal force components of a quartering wind will be smaller than the corresponding forces caused by the same wind blowing a beam or head on.

The calculation for wind and current forces based on OCIMF: Prediction of Wind and Current Loads on VLCC's. [Ref.3]

Lateral wind force determined by Equation:

$$F_{yw} = \frac{1}{2} C_{yw} \rho_w V_w^{\,2} A_L \tag{2}$$

Longitudinal wind force determined by Equation:

$$F_{xw} = \frac{1}{2} C_{xw} \rho_w V_w^{\,2} A_T \tag{3}$$

Longitudinal wind force determined by Equation:

$$F_{xw} = \frac{1}{2} C_{xw} \rho_w V_w^{\,2} A_T \tag{4}$$

Where:

C_{YW}= lateral force coefficient
C_{XW}= longitudinal force coefficient
C_{XYW}= longitudinal force coefficient
A_L = longitudinal area projection (m^2).
ρ_w = mass density of water (kg/m^3)
V_W = wind speed (m/s)
A_T = transversal projected area of the ship (m)

The conversion for wind speed for elevation 10 m given by equation:

$$V_w = u_w \left(\frac{10}{h}\right)^{1/7} \quad (5)$$

where:

V_W = wind speed at elevation 10 m (m/s)
u_W = wind speed at elevation h(m/s)
h = survey elevation (m)

The current force considerations are similar with wind force. Current forces on mooring vessels increases as much as square of the current velocity. Current forces act on the submerged portion of the ship, the most critical when the ship is loaded.

The calculation of current forces use following equation: Lateral current force determined by equation:

$$F_{yc} = \frac{1}{2} C_{yc} \rho_w V c^2 L_{Bp} T \quad (6)$$

Longitudinal current force determined by equation:

$$F_{xc} = \frac{1}{2} C_{xc} \rho_w V c^2 L_{Bp} T \quad (7)$$

Current Yaw Moment determined by equation:

$$M_{XYc} = \frac{1}{2} C_{XYc} \rho_w V_c^2 L_{BP}^2 T \quad (8)$$

Where:

C_{YC} = lateral current coefficient
C_{XC} = longitudinal current coefficient
ρ_w = mass density of water (kg/m3).
T = draft of LNG Tanker (m)
V_C = current speed (m/s)
L_{BP} = length between perpendicular (m)

Mooring modeling using OPTIMOOR, OPTIMOOR is intended for use as a training aid and tool in planning and managing vessel mooring systems. The OPTIMOOR mooring analysis computer program takes input data for a particular vessel and a particular berth and computes the mooring forces produced by defined wind, wave, current, and other forces and changes in draft and tide. The OPTIMOOR user defines the mooring by designating which vessel mooring lines are connected to which berth mooring points.

The calculations are performed almost instantaneously, allowing a number of different mooring, environment, draft and tide situations to be quickly investigated.

Figure 3 and 4 show mooring configuration for LNG Tanker at port and starboard side.

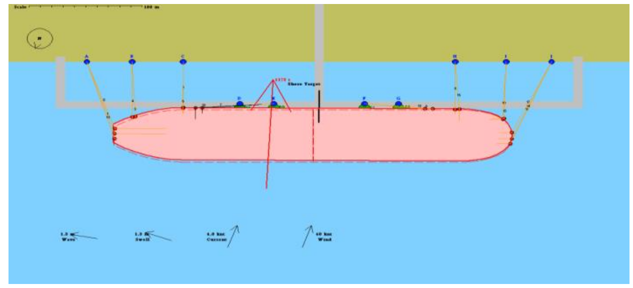


Figure 3 Arrangement plan for port side

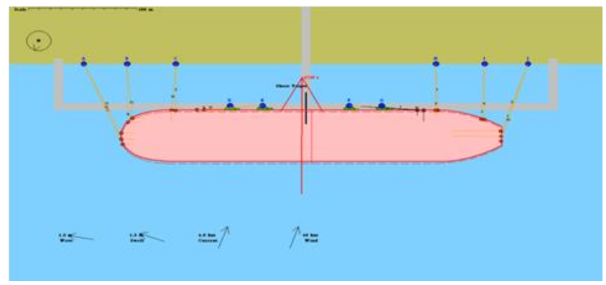


Figure 4 Arrangement plan for starboard side

The detail of mooring line show on Table 4. The arrangement is made by trial and error to define the suitable layout for the vessel. Different vessel will have different mooring line arrangement.

Table 4 Mooring line arrangement

Forward		Aft	
BD3 2 fore-springs	BD2	2 back-springs	
MD4 2 breast-lines		MD3	2 breast-line
MD5 2 breast-lines		MD2	2 breast-lines
MD6 3 head-lines		MD1	3 stern-lines

OPTIMOOR result show the mooring line tension, vessel movement, and mooring force, there are maximum allowable vessel movements for some ship category mention at Table 5 based on [Ref.2].

Table 5 Range for maximum allowable sudden movement

Type	Surge (m)	Sway (m)	Heave (m)	Yaw (deg)
LNG Tanker	±0.2	±0.1	±0.1	0.5

Figure 5 show the RAO drift forces when vessel berthing in LNG Jetty.

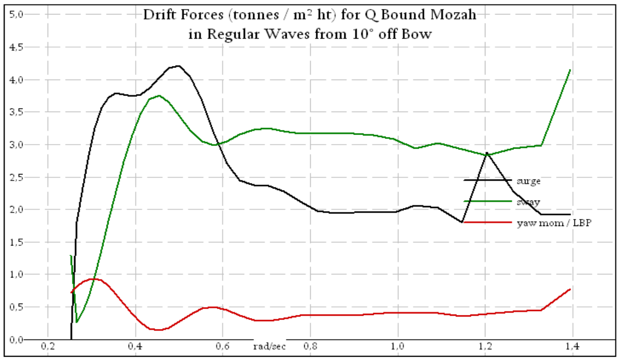


Figure 5 RAO curve drift forces

The detail of Figure 5 show in Table 6. This table show the vessel movement from mooring modeling with OPTIMOOR software.

Table 6 Vessel movement from OPTIMOOR result

Side	Water Level	Vessel Movement (m) Surge	Sway	Yaw	Heave
Port	1.2 LAT	0	2.1	0.3	0.1
		-0.3	2.2	0.5	0.1
		-0.4	2	0.3	0,1
	3.3 LAT	-0.2	1.9	0.4	0,1
		0.1	1.8	0.3	0,1
		-0.4	1.8	0.3	0
Starboard	1.2 LAT	-0.6	2	0.4	0
		-0.3	2.1	0.3	0
		-0.1	2	0.1	0
	3.3 LAT	-0.5	1.7	0.3	0
		-0.3	1.8	0.3	0
		0	1.7	0.1	0

It means that the OPTIMOOR vessel movement bigger than requirement from Table 5, but it doesn't make a lot of effect because the size of both tankers quite large so can handle the vessel movement.

Table 7 show the mooring line tension with wave and current sweep load combination.

Table 7 Mooring line tension

Side	Water Level	Sweep	Mooring Line Direction (deg)	Tension (%)
Port	1.2 LAT	Wind	190	47
		Current	210	49
		Wave	45	42
	3.3 LAT	Wind	200	49
		Current	70	48
		Wave	55	43
Starboard	1.2 LAT	Wind	70	50
		Current	70	40
		Wave	280	35
	3.3 LAT	Wind	70	49
		Current	60	41
		Wave	270	36

From the table above show that all mooring line tension meet requirement of 55% MBL for all kind of iteration.

Table 8 show the mooring force on bollard/Quick Release Hooks used in this study case.

Table 8 Mooring line force on QRH

Hook /Bollard	X-Force (ton)	Y-Force(ton)	Horizontal Force(ton)
A	28.0	89.1	93.4
B	6.2	130.6	130.7
C	-0.5	122.8	122.8
D	-	-	-
E	-151.8	13.3	152.4
F	188.3	16.2	189.0
G	-	-	-
H	4.9	155.5	155.6
I	-7.0	163.6	163.8
J	-46.8	105.2	115.1

Table 8 show the maximum force is 189 tones, regarding of that we choose quick release hooks with capacity 200 tones (SWL) and all the tension below criteria 55% tension MBL. The details are:

- Breasting dolphin using triple quick release hooks with capacity 200 tones (SWL)
- Mooring dolphin using quadruple quick release hooks with capacity 200 tones (SWL)

5.0 IGNITION RANGE DISPERSION ANALYSIS

Design LNG jetty should consider of the possible LNG gas leakage accident. The range of flammable gas cloud dispersion generated by gas spill depends on spill rate and duration. The ignition free zones determined by dispersion analysis under variety of weather conditions.

The dispersion analysis use heat transfer and transport theorem show on equation below:

$$\frac{\partial C(x,y,t)}{\partial t} = \alpha\left(\frac{d^2C(x,y,t)}{dx^2} + \frac{d^2C(x,y,t)}{dy^2}\right) - v\left(\frac{\partial C}{\partial x} - \frac{\partial C}{\partial y}\right) \quad (9)$$

Where:

α = dispersion gas coefficient
v = dispersion rate
C= concentration

The gas flow velocity of gas leakage from outlet decreases as air drawn into the plume. The atmosphere will decrease hydrocarbon gas concentration and hence the gas density of the flume. The gas flow decreases in velocity, hydrocarbon concentration and density mixed with climate condition such as wind speed and meteorological factors, and determine the final shape of the plume and hence of the flammable zone. The pattern of flume on different loading rate and height of deck, show on Figure 6. The figure show that the velocity and total flow rate of dispersion gas is depend on the wind velocity and also deck level.

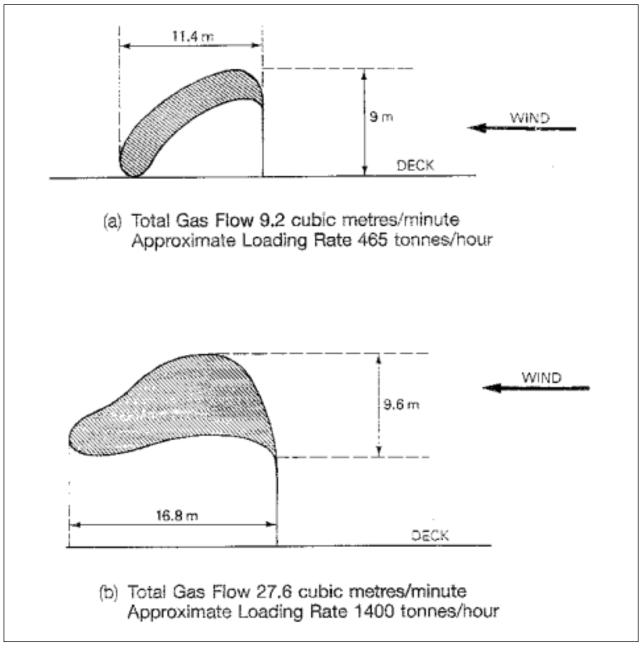


Figure 6 Flow rate on different loading rate [Ref.5]

There are some characteristic that influence the dispersion gases such as wind speed, flow gas rate, hydrocarbon gas concentration and cross sectional area at opening leakage.

After certain distance, gas hydrocarbon concentration will passes below the LFL (Lower Flammable Limit). When hydrocarbon concentration reaches level below LFL, it ceases to be concern as flammability hazard because it cannot be ignited.

The measurement of hydrocarbon vapour on tanker and LNG terminal based on two categories:

1. The measurement of hydrocarbon gas in air below LFL.

This criterion is to detect the presence of flammable (potentially explosive) vapours and to detect concentrations of hydrocarbon vapour that might be harmful to personnel. The percentage of the concentration usually recorded as %LFL. The instruments used to measure %LFL are catalytic filament combustible gas indicators, which are usually referred to as Flammable Gas Monitors.

2. The measurement of hydrocarbon gas as a percentage volume of the total atmosphere

Tanker usually carried out to measure the percentage of hydrocarbon vapour in an inert atmosphere. Instruments used to measure hydrocarbon vapours in an inert gas atmosphere are specially developed for this purpose. The readings obtained are expressed as the percentage of hydrocarbon vapour by volume and are recorded as % VOL.

Modeling ignition range dispersion use CIRRUS software.CIRRUS is a software package which was developed by BP International Limited, London and others. The purpose of the package is to provide a standard and validated set of consequence models which can be used to predict the effects of a release of hydrocarbon or chemical liquid or vapour.

There are some characteristic needs to be considered on vapor dispersion modeling:

1. Atmosphere stability and wind speed

The dispersion modelling assumes the wind speed at 10 m height and happen on neutral atmosphere stability. Neutral stability will occur when air is mixed, for example at a reasonable wind speed, or when there is no temperature instability due to extensive cloud cover.

2. Surface roughness

The surface roughness parameter influences the wind speed and turbulences on this area.

3. Toxicity and flammability limit

This will be the lower concentration for which the model determines plume widths. Concentrations should be expressed as volume percentages of the released material. For heavy gas release containing a contaminant with initial concentration, y(volume/volume), the plume profile of the contaminant dispersed down to a concentration x (volume/volume) in air can be evaluated by specifying a concentration of interest relevant to the contaminant x/y. Based on [Ref.5], the LFL for methane is 5%volume/volume and UFL value for methane is 15%volume/volume.

4. Sampling Time

The dispersion models aim to show a 'time averaged' concentration at a particular point, this average will depend on the length of time over which the concentration was 'sampled'. Minimum value 30 s and maximum value is 1 hour. Input for the dispersion analysis using assumption such as:

- Dispersion behaviour type is Heavy Vapour Dispersion because the vapour cloud is denser than air.
- Low Temperature of LNG at -162C it is heavier than air and will hug the ground.
- Concentration gas type is Continuous Steady State Release.
- Type of gas is Methane
- Leakage source type is liquid tank because LNG is transported using LNG carrier with low temperature.
- Tank system is maintained Pressure Head.

Software CIRRUS shows the hydrocarbon concentration and methane dispersion range. The result is location where LFL concentration happens and prediction of volume and times for vapour spreading.

Figure 7 until Figure 11 will show the dispersion analysis result with CIRRUS software.

1. Concentration of LNG spilled

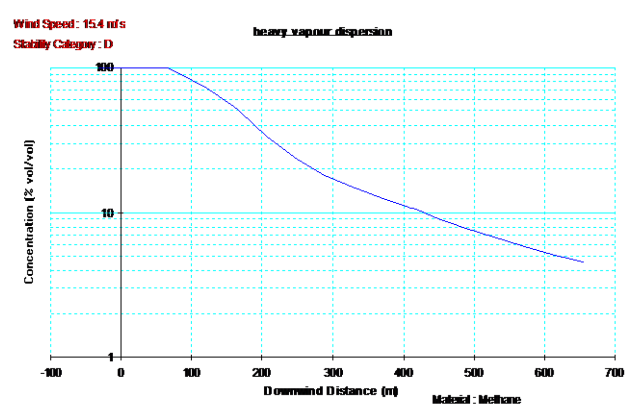


Figure 7 Concentration of LNG spilled vs range dispersion

The Figure 1 show us that concentration 15% volume/volume (UFL methane) happen at distance 350 m and concentration 5%volume/volume (LFL methane) happen at distance 650 m.

2. Dispersion Distance of LNG Spilled

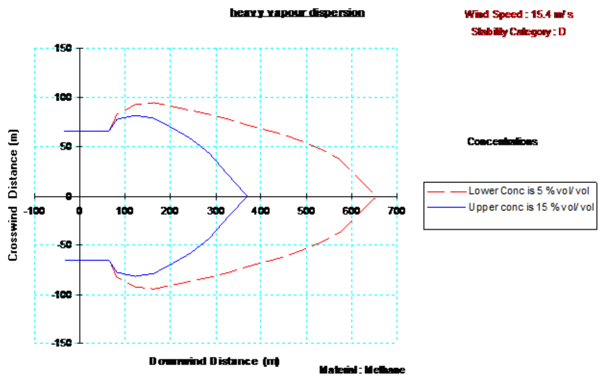


Figure 8 Comparison graphic UFL and LFL concentration

Figure 7 show that the sterilization zone is area after 650 meter from centre of spill location.

3. Height of Vapour Dispersion

Figure 8 shows that the comparison of vertical distance and height of vapour dispersion in these analysis.

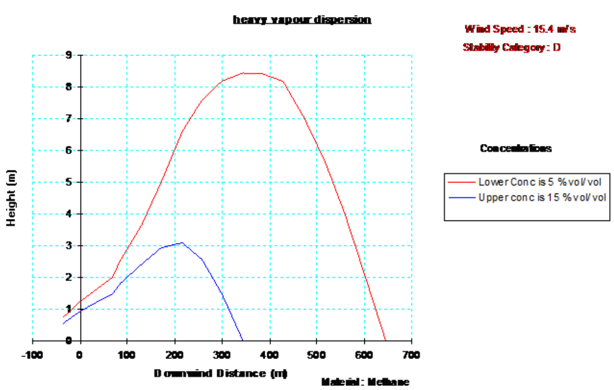


Figure 9 Comparison of height versus downwind dispersion distance

4. Dispersion Flow Rate

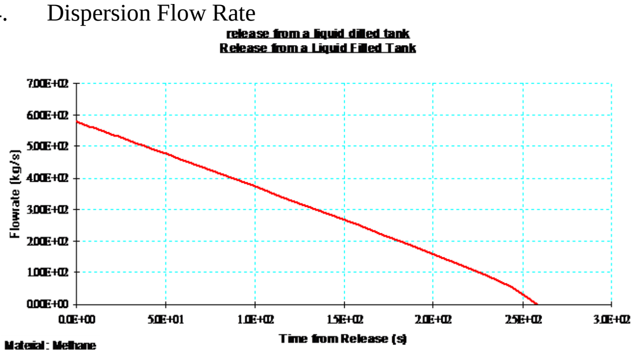


Figure 10 Flow rate vs dispersion gas

The graphic show us that flow rate is 600 kg/s and will be zero after 252 s.

5. Cumulative Mass Flow

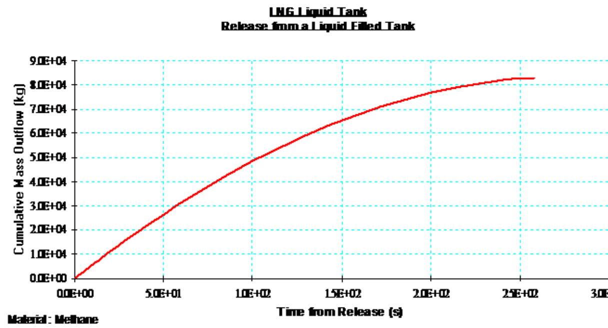


Figure 11 Cumulative mass flow

The graphic on Figure 11 show us that after 250 s the cumulative mass outflow is 82,500 kg.

Figure 12 show the location of new LNG jetty near existing jetty facilities.

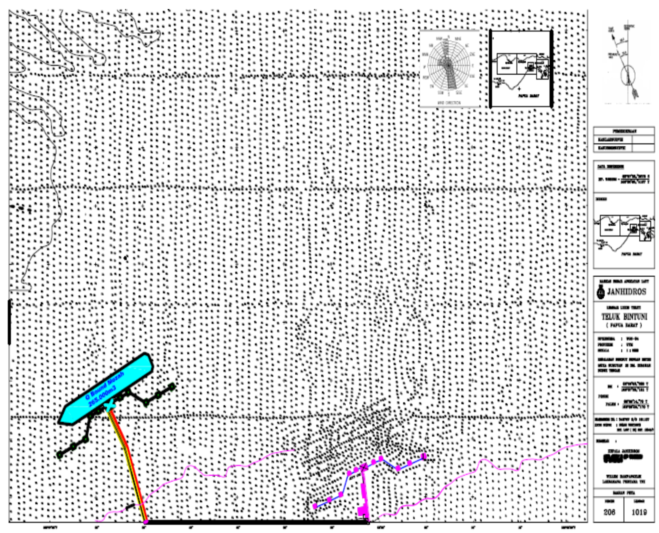


Figure 12 LNG jetty location

6.0 CONCLUSION

1. The site selection consider about tanker's draft and the result of dispersion gas model with CIRRUS. The safety zone from ignition risk is area outside radius 650 m from loading platform where LNG spilled.
2. From analysis OPTIMOOR, it concludes that the suitable mooring lines for the vessel are *steel wire steel core* with mooring tail nylon 3 or 8 *strand (broken-in).* The configuration has fulfilled requirement from OCIMF which is to have highest mooring line tension below 55% and need QRH with capacity 200 ton.

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