2023

Guidelines for Liquefied Natural Gas Dispersion Analysis

KR

2023

Guidelines for Liquefied Natural Gas Dispersion Analysis

GL-0033-E

KR

APPLICATION OF "GUIDELINES FOR LIQUEFIED NATURAL GAS DISPERSION ANALYSIS"

1. Unless expressly specified otherwise, the requirements in the Guidelines apply to Gas Dispersion Analysis for which request of the Client is made on or after 01 January 2023.

CONTENTS

CHAPTER 1 INTRODUCTION

Section 1 General

101. Application

1. This guidelines describe the procedures and requirements for the dispersion analysis of liquefied natural gas(LNG) from the vent mast or other vent outlets under the hazardous scenario that may occur during system operation.
2. LNG dispersion analysis described in this guidelines may be applicable to various equipment and systems, including ship design, but are not limited to specific technical and regulatory fields.

102. Overview

1. When an accident occurs or maintenance for related equipment is required in a process system handling hazardous materials such as LNG, pressurized gas may be discharged through the vent mast or other vent outlets to decrease the pressure of system for accident prevention. As a result, equipment around the vent outlet may break down or accidents such as fire or explosions may occur due to ignition sources. Also, operators for LNG transfer or bunkering operation and the general public outside the workplace may inhale the dispersed gas and cause damage of human life such as suffocation.
2. As soon as LNG is discharged from the vent mast or other vent outlets, it starts mixing with the atmosphere air. At this time, based on the concentration of the flammable(explosive) range of the gas, as shown in Figure 1, the upper flammable limit(UFL) or upper explosive limit(UEL) and lower flammable limit(LFL) or explosive lower limit(LEL) is determined. The lower and upper flammable limits of methane, the main component of LNG, is known to be 4.4 vol% and 16.4 vol% in air, respectively. As the LNG discharged from the vent mast or other vent outlets moves away from the outlet, the gas concentration gradually is lower. The size or extent of the flammable gas cloud can be determined to the point where the gas concentration is below than lower flammable limit(LFL).
3. The shape and size of the flammable gas cloud developed by the LNG discharged from the vent mast or other vent outlets is affected by various conditions such as the flow rate, pressure of the discharged LNG or ambient temperature, wind direction, and wind speed. Therefore, the LNG dispersion analysis should be conducted with scenario selection in which the flammable gas cloud is developed as the largest, or closest to the area where safety is to be ensured, such as accommodation or muster area for emergency escape and evacuation.
4. Based on the results of LNG dispersion analysis, the range of the flammable gas cloud can be estimated, a flammable(explosive) zone in which a fire or explosion may occur. That is the range between the upper explosive limit(UFL) and lower explosive limit(LFL) in the vicinity of the vent mast or other vent outlets can be derived by LNG dispersion analysis. Hence the ship or system should be designed in consideration of these risks.
5. In addition to the vent outlet through which the LNG is discharged, and indoor area where the discharged LNG can be impinged through a door or HVAC intake, and an adjacent deck area may be flammable area. Therefore, by considering these risks, the adequacy of the location and height of the vent mast or other vent outlets should be evaluated.

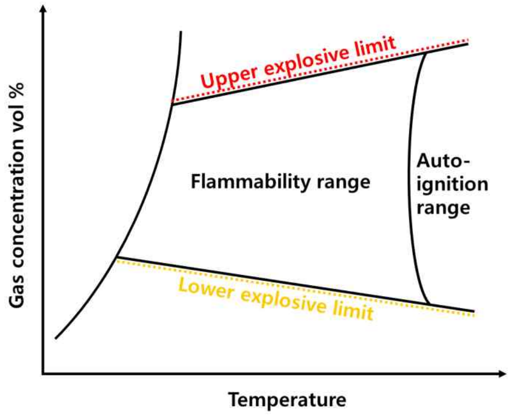

Figure 1 Flammable(explosive) range of gas

103. What is LNG dispersion analysis?

1. The LNG dispersion analysis can estimate the results of shape and size of the flammable gas cloud developed by the dispersion of LNG discharged from the vent mast or other vent outlets in normal or abnormal scenarios in system operation.

104. Purpose of LNG dispersion analysis

1. It is possible to improve the overall understanding of design and operational concept of related systems such as the vent mast or other vent outlets for LNG dispersion analysis.
2. It is possible to identify risk scenarios for LNG dispersion analysis and to improve the understanding of environmental conditions.
3. It is possible to improve the understanding of dispersion analysis model such as Integral and Computational fluid dynamics(CFD) for the LNG dispersion analysis, and the shape and range of the flammable gas cloud can be estimated with the results of LNG dispersion analysis.
4. It is possible to review the overall safety aspect of the current design of the target system based on the results of LNG dispersion analysis, and they can be used to evaluate the adequacy of the location and height of the vent mast or other vent outlets as well.

105. Execution time of LNG dispersion analysis

1. The appropriateness of height or location of vent mast or other vent outlets can be determined based on the shape and range of the combustible gas cloud that can be estimated through the results of LNG dispersion analysis, and the arrangement of vent outlet may be changed at this time. Therefore, it is valid to conservatively apply to development and arrangement of related systems including the vent mast or other vent outlets based on the results of the LNG dispersion analysis in the early stages of system development, conceptual design or basic design stage. Afterwards, it is most effective and desirable to revise the LNG dispersion analysis at the detailed design stage when the design and arrangement of system and ship are almost settled, and to review the design and arrangement according to the revised results of LNG dispersion analysis.

106. Related rules

1. According to “Section 7 Pressure Relief System, Chapter 6, KR Rules for the Classification of Ships Using Low-flashpoint Fuels(2022)”, the outlet from pressure relief valve to be arranged higher than B/3 or 6 m above the weather deck or 6 m above working areas and walkways.
2. According to “Section 7 Pressure Relief System, Chapter 6, KR Rules for the Classification of Ships Using Low-flashpoint Fuels(2022)”, the outlet from pressure relief valve to normally be located at lease 10 m from the nearest accommodation, service and control spaces, air intake, etc.
3. According to “Section 5 Hazardous Area Zones, Chapter 12, KR Guidance Relating to the Rules for

the Classification of Ships Using Low-flashpoint Fuels(2022)", the size of hazardous area from vent outlet from 6 m to 3 m in case of zone 1, and from 4 m to 1.5 m in case of zone 2 based on a gas dispersion analysis.

Section 2 Terms and Definitions

201. Terms and definitions

1. **Accidents** means unforeseen events that may entail the loss of human life, personal injuries, environmental damage or the loss of assets and financial interests.
2. **Concentration** means the amount of a specific substance present in a certain area or volume. The unit of concentration is very various, such as mass percentage, volume fraction, mass concentration, and molar concentration. The unit of concentration mentioned in this guideline is mainly volume fraction, which means the volume fraction of a specific substance with respect to the volume of the whole mixture.
3. **ESD** is an abbreviation of "Emergency shut-down", and a function that can shut off the system to prevent greater economic and social damage caused by incidents such as loss of containment under abnormal circumstances.
4. **Frequency** means the number of occurrences per unit time. (e.g., 10 times per annum)
5. **Hazard** means a potential to provoke a negative impact on human, environment, or asset. A hazard may occur from a range of causes, and result in a range of consequences.
6. **Hazardous area** means an area in which an explosive gas atmosphere is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment.
7. **Hazardous scenario** means a sequence of accident from a specific cause to a specific consequence.
8. **HAZID**, which is an abbreviation to 'hazard identification', is one of the qualitative risk analysis methods based on expert judgement, and identifies potential hazards or hazardous events likely to cause loss or damage to human, environment, or asset during the operation of target system in a systematic manner, and then draws and proposes risk reduction measures to lower the risk levels of hazards or hazardous events identified below an allowable level.
9. **Incident** is an unexpected event that does not cause damage, such as loss of life or injury, but has potential to cause.
10. **Individual Risk** is the estimated annual frequency of individual fatal due to a specific risk.
11. **LEL / UEL** is an abbreviation of "Lower explosive limit / Upper explosive limit", indicating the lower explosive limit and upper explosive limit. LEL means that the concentration of a mixture is low in air and can not ignited below this specific concentration. Exceeding the UEL means that the concentration of the mixture in the air is too high to be ignited. These can also be called LFL / UFL, and is an abbreviation of "Lower flammable limit / Upper flammable limit".
12. **Liquefied natural gas(LNG)** is an abbreviation of "Liquefied natural gas" and refers to liquefied natural gas generated during the process of liquefying methane obtained by refining natural gas produced from a gas field.
13. **Personal protective equipment(PPE)** is an abbreviation of "Personal protective equipment" and means protective equipment such as gloves, masks, and goggles to protect personnel against unexpected hazardous incidents.
14. **Risk** is the degree combining the frequency of accident occurrence(or accident causes) that can cause loss to people, the environment, and assets and the consequence of accident.

Section 3 Model and Software for LNG Dispersion Analysis

301. Overview

1. The incidents of discharge of toxic or flammable materials, including LNG, may cause a series of accident escalation such as fire and explosion, and there is a risk of personal injury or equipment damage as well. Therefore, by predicting the concentration of toxic or flammable materials likely to be discharged from the related system based on LNG dispersion analysis, the degree of risk can be identified and ensure the safety.
2. Discharge and dispersion of hazardous materials including LNG may be instantaneously changed by physical properties accompanied by thermodynamic action and phase change due to interaction with conditions such as adjacent structures. In addition, environmental conditions such as wind speed and direction can not be maintained constantly while hazardous materials are discharged from outlet. As such, these various variables are organically involved in gas dispersion, it is practically impossible to conduct the modeling of dispersion analysis that is exactly same as actual dispersion on experiments or phenomena.
3. There are various analysis models that can be used to predict the discharge and dispersion of LNG or other hazardous materials. They have been continuously developed through laboratory or field research experiments in academia and industry. The model types for LNG dispersion analysis can be classified into three types; Workbook, Integral and CFD. The representative software for LNG dispersion analysis are shown in Table 1. Some of these models are open to the public for free, but most models are commercialized and paid purchase is required.

Table 1 Overview of model for LNG dispersion analysis

Model type	Software
Workbook	“Workbook on the dispersion of dense gases”(Britter and McQuaid)
Integral	ALOHA(EPA), BREEZE(Trinity), CANARY(Quest), DRIFT(ESR Tech.), EFFECTS(TNO), GASTAR(CERC), HEGADAS(Shell), PHAST(DNV), SAFER TRACE(SAFER Systems), SLAB(EPA), SUPERCHEMS EXPERT(IoMosaic)
CFD	CFX(ANSYS), FDS(NIST), FEM3A(Arkansas Univ.), FLACS(GexconAS), FLUENT(ANSYS), in:Flux(Insight Numerics), OpenFOAM(OpenFOAM), PANACHE(Fluidyn), STAR CCM+(Siemens)

302. Workbook model

1. The Workbook model, also called engineering correlation or empirical correlation, is a model that can estimate the results with associating the numerical variables through empirical relationships based on the assumption that derived relationships are applicable and sustainable under different each conditions. Well-known example is the equation and nomo-graph suggested by R E Britter and J McQuaid in the ‘Workbook on the dispersion of dense gases(1989)’. They collected the results of many laboratory/field research experiments on dispersion of high dense gases and suggested a dimensionless nomo-graph that is most appropriate to the resulting data. The gas concentration can be estimated based on correlations such as downwind distance, physical variables such as initial/average gas concentration, density, etc. through the suggested Workbook model. This model can estimate the results of dispersion analysis very speedy and simply, if the analysis target is appropriate on the suggested data. On the other hand, this model can be applied only to a simple case, the results can be significantly different against the actual experimental data if the modeling a scenario deviates from the suggested data in the Workbook.

303. Integral model

1. The Integral model assumes that the gas cloud has a dense central core and the edge of gas cloud has a Gaussian distribution on the sides. Based on this assumption, the results such as radius, velocity, temperature and gas concentration of gas cloud properties can be estimated through ordinary differential equations. Integral model can not only take into account simple topographical characteristics such as uniform slope, but also conduct simple analysis such as heavy gas

dispersion, passive dispersion and temperature effects. In addition, Integral model has the advantages of being easy for users to use and the short time for dispersion analysis. However, since it follows the logic based on a existing specific assumptions for model of dispersion analysis, additional verification stage is required to conduct the dispersion analysis with newly introduced assumptions that are not included in established logic such as obstacles or terrain of complex shapes.

304. CFD model

1. The Computational fluid dynamics(CFD) is a discipline that has began in aerospace science in the 60's. Currently, it has been used in most field of engineering and science, and to predict and analyze the fluid flow by calculating various thermodynamic and chemical equations including the the governing equation, Navier-stokes equations. In the case of LNG dispersion scenarios with complex adjacent structures and various other conditions, the shape and range of flammable gas clouds can be predicted and analyzed by CFD model.

2. Unlike the integral model, which uses ordinary differential equations to describe the volume characteristics of the entire gas cloud, in the case of CFD, characteristics of gas clouds in individual grids are calculated and estimated through numerical analysis with the Navier-stokes equation on the space and time through discretization by appropriate methods, such as finite element method(FEM), finite volume method(FVM), etc. And the effect of surrounding conditions such as complex topography and ambient meteorological conditions on the flow and dispersion of gas cloud can be clearly represented compared to the Integral model. As such, the CFD model can estimate more accurate analysis results in time and space than other models. However it has disadvantage of being expensive, including purchasing a CFD software, building a workstation, and providing specialized training for more elaborate analysis. In particular, understanding of various conditions and equations for analysis modeling is important, because even if the same CFD software is utilized for the same scenario, the analysis results may be different when the dispersion analysis conducted by different users. And although analysis with finer girds can estimates more accurate results, it can take hours, days, or weeks to complete the dispersion analysis depending on the number of grid cells and the congestion level of the 3D model. Hence, a major disadvantage is that it takes a lot of time for producing the elaborate analysis results. ⚓

CHAPTER 2 LNG DISPERSION ANALYSIS CONDUCT

Section 1 Procedure for LNG Dispersion Analysis

101. Overview

1. Procedure for LNG dispersion analysis is as follows.
(1) LNG dispersion analysis preparation
(2) LNG dispersion analysis conduct
(3) Follow-up work on LNG dispersion analysis

2. The outline of procedure for LNG dispersion analysis is shown in Figure 2.

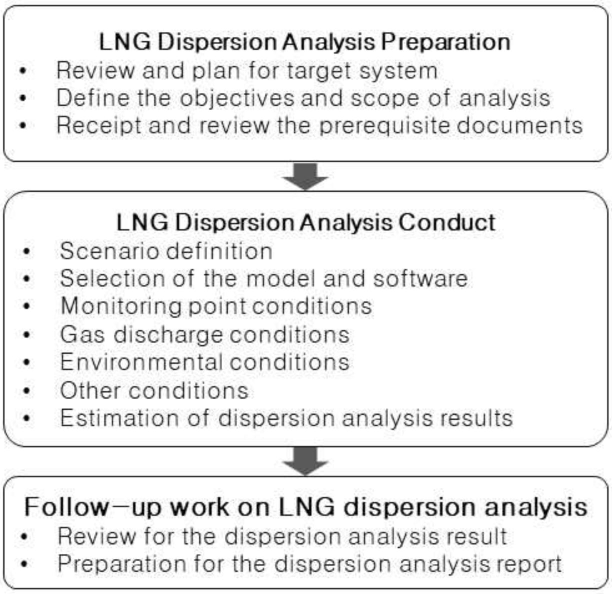

Figure 2 Procedure for LNG dispersion analysis

Section 2 LNG Dispersion Analysis Preparation

201. Review and plan for target system

1. The person in charge of LNG dispersion analysis and the client complete the administrative procedures to commence the task.

2. The person in charge of LNG dispersion analysis receives the data and documents described in 203. Prerequisite documents below from the client and figure out the basic concept of design, arrangement and operational concept for the target system.

3. The person in charge of LNG dispersion analysis establishes a progress plan for the task, and for this purpose, 105. Execution time of LNG dispersion analysis in Chapter 1 can be referred.

202. Define the objectives and scope of analysis

1. Define the objectives and scope to efficiently conduct the LNG dispersion analysis.

2. In order to define the objectives and scope of the LNG dispersion analysis, 103. What is LNG dispersion analysis? and 104. Purpose of LNG dispersion analysis in Chapter 1 can be referred.

203. Prerequisite documents

1. In order to effectively conduct the LNG dispersion analysis, relevant data and document to understand the overall concept of design, arrangement, and operational concept for the target system should be provided to the person in charge of LNG dispersion analysis, and at least the following data should be included but not limited to.

(1) General arrangement
(2) Hazardous area classification
(3) Layout for the fire and gas detectors
(4) HVAC layout
(5) Process flow diagram (PFD)
(6) Piping and instrumentation diagram(P&ID)
(7) Documents related to target system
(8) Documents related to operational concept and maintenance of target system
(9) Documents related to gas dispersion to the atmosphere, such as calculation sheet for pressure relief valve, etc.
(10) Detailed drawing for vent mast or other vent outlets

2. In order to conduct the LNG dispersion analysis, data related to the environmental conditions of the seas or field where the target system would be operated should be prepared, and at least the following data should be included but not limited to.

(1) Wind direction and speed data
(2) Ambient temperature data
(3) Atmospheric stability data
(4) Relative humidity data
(5) Surface roughness data

3. Review wheter the documents received for the LNG dispersion analysis are appropriate for the conduct analysis, and check whether additional document is required.

Section 3 LNG Dispersion Analysis Conduct

301. Overview

1. LNG dispersion analysis is conducted after defining the following input. However, this may be different depending on the type of the model and software for analysis.

(1) Scenario definition
(2) Selection of the model and software
(3) Monitoring point conditions (monitoring point, concentration of interest, averaging time)
(4) Gas discharge conditions (gas discharge flow rate, pressure and composition, outlet diameter, direction and height)
(5) Environmental conditions (wind direction and speed, ambient temperature, atmospheric stability, relative humidity, surface roughness)
(6) Other conditions (Geometry, Grid)

302. Definition and assumption for input

1. LNG dispersion analysis is not a verification task for an accident that has already occurred, but a analysis task to prevent accidents and minimize damage in preparation for potential accident scenario. Therefore it is necessary to prepare a LNG dispersion analysis by presupposing a scenario in which an accident with a high probability or the worst accident can occur among several potential accident scenario.

2. It is necessary to define the input along with assumption, scenario definition, selection for the analysis model and software, and conditions for monitoring point, gas discharge, environmental and others. This should be determined through agreement between the person in charge of the dispersion analysis and the client, and then the task can be conducted.

303. Scenario definition

1. Scenarios are defined by considering various requisite such as gas leak conditions(gas flow rate, pressure, composition, etc.) and environmental conditions(wind direction, speed, etc.). LNG dispersion scenario selected through a qualitative risk assessment technique such as HAZID can be utilized for definition. In particular, it is necessary to select the worst-case scenarios and then conduct the LNG dispersion analysis. There are scenarios that would discharge the most LNG, or LNG discharge would form the flammable cloud closest to the areas where safety must be ensured, such as accommodation,

2. For instances, total 24 scenarios can be selected for the following conditions, and LNG dispersion analysis must be conducted for all selected scenarios; 2 conditions of discharge gas flow rate, 3 conditions of wind speed, 2 conditions of ambient temperature and 2 conditions of atmospheric stability. However, agreement between the person in charge of LNG dispersion analysis and the client to be required.

304. Selection of the model and software

1. Based on the selected scenario, which analysis model and which analysis software to conduct the LNG dispersion analysis, agreement between the person in charge of task and the client to be required for selection of the analysis model and software. Section 3 in Chapter 1 can be referred for this selection.

2. Monitoring point conditions, gas discharge conditions, environmental conditions and other conditions described in the following paragraphs are general descriptions of input mainly utilized for LNG dispersion analysis, and the person in charge of the task can refer to these information. However, since there are many dispersion analysis model and software, and input and analysis methodology may be different, it is suggested to conduct the LNG dispersion analysis by complying with the recommendations from selected software.

305. Monitoring point conditions

1. Monitoring point

(1) The monitoring point is a user-defined location where one or more variables such as concentration and temperature can be monitored in the LNG dispersion analysis model.

(2) The location of monitoring point may be an area close to a vent mast or other vent outlet, muster area for emergency escape/evacuation, HVAC intake of accommodation, not classified area as hazardous area, or area where operator reside or locate frequently.

(3) The location can be determined by agreement between the person in charge of task and the client.

2. Concentration of interest

(1) In order to form a flammable gas cloud through LNG dispersion analysis model, it is necessary to define the target concentration of interest.

(2) In order for the flammable gas cloud to be ignited by an ignition source, the concentration of the flammable gas cloud formed by LNG discharge may have a value between the lower limit of flammable(LFL) and upper limit of flammable(UFL). Hence a flammable gas cloud can be formed based on these values.

(3) It can be noted that, in addition to using the 100% of LFL as an effective safety criterion, a 50% of the LFL can be used as per Webber.

(4) The concentration of interest must be determined by agreement between the person in charge of task and the client.

(5) For reference, several concentrations of interest can be used when conducting the dispersion analysis on toxic gas clouds, the National Institute for Occupational Safety and Health (NIOSH) IDLH (Immediately Dangerous To Life or Health) and Recommended Exposure Limits (REL), and Permissible Exposure Limits (PEL) of the Occupational Safety and Health Administration (OSHA) of the United States.

3. Averaging time

(1) When gas is continuously discharged, the gas cloud fluctuates from the central axis of gas discharge due to turbulence and wind, which is called passive dispersion. In order to properly

represent the shape of the gas cloud, the average concentration with respect to time can be expressed as a Gaussian distribution as shown in Figure 3.

(2) In most studies, the shape of the gas cloud is expressed using an average time of 10 minutes. On the other hand, in the case of a cloud of combustible gas, an instantaneous flame can be generated, so the dispersion analysis should be performed using the minimum short time as the averaging time to build up the flammable gas cloud. It can be noted that many research have defined 18.75 seconds as the averaging time for flammable gas cloud.

(3) For reference, in the case of dispersion analysis of a toxic gas cloud, various averaging times can be used considering the concentration of interest. For example, it can be regarded as 1,800 seconds for IDLH and 8 hours (total weight average, TWA) for PEL.

(4) As the shape of the gas cloud may change depending on the averaging time, the definition of the averaging time must be determined by agreement between the person in charge of task and the client.

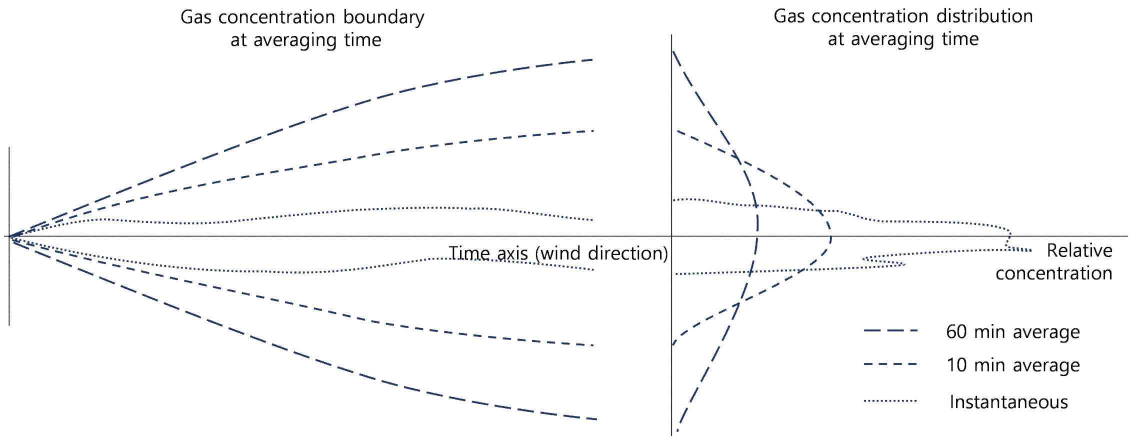

Figure 3 Gas concentration boundary and distribution at averaging time [Seinfeld, 1986]

306. Gas discharge conditions

1. Gas discharge flow rate and pressure

(1) Results of LNG dispersion analysis may be differed depending on the flow rate and pressure of gas discharge through the vent mast or other vent outlet.

(2) As the discharge flow rate and pressure of LNG increase, the velocity of the discharged gas increases and is diluted to a concentration of LFL or less at a farther distance from the vent outlet, so the flammable gas cloud would be longer and larger.

(3) As the kinetic energy is higher, the dispersion of discharged LNG make the jet shape. At the same time, it can be noted that the higher the flow rate of the discharged gas, the more efficiently the mixture of the discharged gas and air occurs.

2. Gas discharge composition

(1) Results of LNG dispersion analysis may be differed depending on the components of LNG discharged from storage tanks, vent mast, or other vent outlet.

(2) If there is no information on gas composition, it can be used for LNG dispersion analysis by assuming that methane, the main component of natural gas, is 100% of the gas composition.

(3) In addition, if the temperature of the discharged LNG is various according to the condition, the temperature condition in which the size of flammable gas cloud be maximum can be utilized for conducting the LNG dispersion analysis.

3. Outlet diameter

(1) The diameter of the vent mast or other vent outlet can be used for LNG dispersion analysis by referring to the data such as drawing and arrangement.

(2) The velocity of discharged LNG is determined from the provided outlet diameter, and since the mixing ratio of gas and atmosphere is changed depending on the gas velocity, it can be noted that the diameter of the vent outlet affects the size of the flammable gas cloud.

(3) In general, appropriately smaller diameter vent outlets can provide higher gas velocities and contribute to greater dispersion into the atmosphere as LNG is discharged.

4. Outlet direction

(1) The discharge direction of the vent mast or other vent outlet can be used for LNG dispersion analysis by referring to the data such as drawing and arrangement.

(2) Since methane gas, the main component of LNG, is lighter than air, it has floating properties when discharging LNG. Therefore, it can be noted that the shape and size of the flammable gas cloud may vary depending on the direction of the vent outlet.

5. Outlet height

(1) The height of the vent mast or other vent outlet can be used for LNG dispersion analysis by referring to the data such as drawing and arrangement.

(2) The flow of the dispersed gas is affected by the turbulence that occurs in the structures around the outlet. Since the discharged gas forms a vortex due to turbulence and may have difficulty in dispersion, it can be seen that the height of the vent outlet affects the shape and size of the flammable gas cloud.

307. Environmental conditions

1. Wind direction and speed

(1) Wind can have a great effect on the LNG dispersion, and the main wind characteristics are wind direction and wind speed.

(2) For LNG discharged vertically from a vent mast or other vent outlet, it rises and forms a flammable gas cloud like a column. On the other hand, when wind blows, it can be seen that the shape of the flammable gas cloud is bent depending on the wind, affecting the gas dispersion.

(3) When it discharges through a vent mast or other vent outlet, the flow rate and pressure of the LNG are maximum. However, as the gas moves away from the vent outlet, the gas and air mix actively with reducing the gas concentration and thus decreasing the density of the flammable gas cloud. Therefore, the concentration of the LNG discharged from the vent outlet decreases with the wind, which determines the range of the flammable gas cloud.

(4) Data of the wind direction and speed on the target area during the observation period is mainly presented as the wind rose as shown in Figure 4, which is a polar coordinate diagram showing the frequency of wind direction and speed appearance on the bearing plate as the length of the bearing line. However, the frequency of appearance of calm (condition of wind speed less than 0.4m/s) is presented by a number in the center of the graph without considering the wind direction.

(5) For wind rose, data suitable for the target area condition should be used, and the observation period is various, such as one month, one year, or 30 years, so it can be used as needed. However, the data for a observation period that is not too short in consideration of the ship operation life cycle, etc. should be used for LNG dispersion analysis by composing the worst-case scenario in which the shape and size of the flammable gas cloud are the most dangerous.

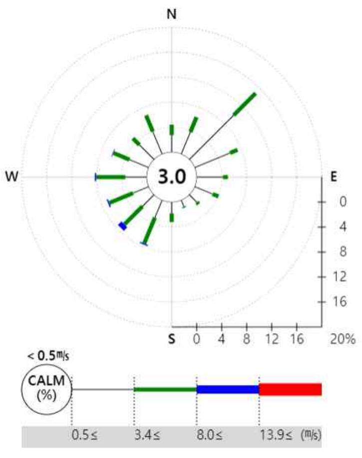

Figure 4 Wind rose [Korea Meteorological Administration]

2. Ambient temperature

(1) Ambient temperature is one of the factor that can affect the results of LNG dispersion analysis.

(2) The temperature of the atmosphere affects the density of the gas. As the temperature decreases, the movement speed of the LNG decreases and the gas density becomes relatively higher.

(3) When LNG is discharged at the vent outlet in the liquid state or in two-phase of liquid and gas, the temperature is very low, so the density of the LNG discharged gas cloud may increase and the flammable gas cloud may tend to go further down.

(4) For ambient temperature, data suitable for the target area condition should be used, and the observation period is various, such as one month, one year, or 30 years, so it can be used as needed. However, the data for a observation period that is not too short in consideration of the ship operation life cycle, etc. should be used for LNG dispersion analysis by composing the worst-case scenario in which the shape and size of the flammable gas cloud are the most dangerous.

3. Atmospheric stability

(1) Atmospheric stability is one of the factor that can affect the results of LNG dispersion analysis.

(2) The atmospheric stability affects the mixture of gas. It is considered that the more stable the atmosphere, the less gas mixture, and the more unstable the atmosphere, the greater the gas mixture.

(3) Pasquill's atmospheric stability class(1961) in Table 2 can be used for LNG dispersion analysis, an important indicator to describe the degree of atmospheric mixing, represented as the relationship between solar insolation and wind speed(day-time) and between cloudiness and wind speed(night-time). The strong insolation referred to in this class corresponds to a sunny noon condition in the UK in midsummer, and a slight insolation corresponds to the condition in midwinter, and in the case of nighttime, it means the time from 1 hour before sunset to 1 hour after sunrise. And there are total 6 classes as following; grade A “very unstable”, grade B “unstable”, grade C “slightly unstable”, grade D “neutral”, grade E “slightly stable”, and grade F “slightly stable”

(4) For atmospheric stability, data suitable for the target area condition should be used, it can be used for LNG dispersion analysis by composing the worst-case scenario in which the shape and size of the flammable gas cloud are the most dangerous.

Table 2 Pasquill’s atmospheric stability class

Wind speed* (m/s)	Solar insolation			Night time	
	Strong	Moderate	Slight	≥4/8(Cloudiness)	≤3/8(Cloudiness)
≤ 2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
≥ 6	C	D	D	D	D

* Wind speed at a height of 10 m

4. Relative humidity

(1) Relative humidity is one of the factor that can affect the results of LNG dispersion analysis.

(2) Water vapour in the atmosphere can have a significant effect on flammable gas clouds because the water vapour can condense as air entrainment into the gas cloud.

(3) In dry air, the gas dispersion is not significantly affected by maintaining the same density at most locations of the flammable gas cloud. On the other hand, the higher the relative humidity, the more active dispersion of low concentration part inside the flammable gas cloud. That is, when the humidity is high, the behavior of dispersion of flammable gas more actively, and thus the size of the flammable gas cloud may be affected.

(4) For relative humidity, data suitable for the target area condition should be used, and the observation period is various, such as one month, one year, or 30 years, so it can be used as needed. However, the data for a observation period that is not too short in consideration of the ship operation life cycle, etc. should be used for LNG dispersion analysis by composing the worst-case scenario in which the shape and size of the flammable gas cloud are the most dangerous

5. Surface roughness

(1) Surface roughness is one of the factor that can affect the results of LNG dispersion analysis.

(2) In general, wind speed increases as it rises from the ground, and this variation in wind speed according to altitude is called gradient wind speed. Gradient wind speed is affected by various conditions of the topography.

(3) Areas with tall buildings, such as urban areas, have very high surface roughness, which tends to increase turbulence. On the other hand, flat areas, such as coastal or agricultural areas, tend to have relatively stable atmospheric air flow because of low surface roughness. The surface of the sea tends to have a more flat surface roughness than the surface of the land. However, it may have complexity that cannot be seen on land because of the rapid difference in water temperature and topographical conditions such as the coastline. Table 3 presented commonly used as surface roughness values.

(4) For atmospheric stability, data suitable for the target area condition should be used, it can be used for LNG dispersion analysis by composing the worst-case scenario in which the shape and size of the flammable gas cloud are the most dangerous.

Table 3 Typical surface roughness

Topography	Surface roughness(m)
Very smooth, ice or mud	0.00001
open sea	0.0002
Rough pasture	0.01
Fallow field	0.03
Crops	0.05
Few trees	0.10
Many trees	0.25
Forest and woodlands	0.50
Suburbs	1.50
Center of cities with tall buildings	3.00

308. Other conditions

1. Geometry

(1) In case of using the CFD software to conduct the LNG dispersion analysis, it is necessary to establish a geometry.

(2) There is a software that can be directly applied to CFD dispersion analysis at the same time as geometry build-up because CAD software has its own CFD software, but there is another CFD software that need to build geometry with other CAD software.

(3) It is important to build the geometry as in reality based on actual drawings. However, as the geometry increases, there are obstacles that greatly affect the diffusion of LNG exhaust gas. And the time required for analysis increases proportionally. Therefore, it may be reasonable to build the geometry by excluding the components that do not significantly affect the analysis. This should be determined through agreement between the person in charge of the dispersion analysis and the client, and then this task can be conducted.

2. Grid

(1) In the case of using the CFD software to conduct the LNG dispersion analysis, the grid

configuration is important because the CFD model is basically calculating and estimating the characteristics of gas cloud in individual grids.

(2) In general, the simulation volume of CFD analysis is divided into grid cells by a total of 3 sets of grid planes, one in each X, Y and Z axis direction. As the number of grid cells increases, that is, the finer the grid cell, the more accurate the results can be estimated. However, high-performance workstations are required to conduct the LNG dispersion analysis with high-resolution, and it takes a lot of time, so it is important to build the grid at a reasonable level. It is suggested to meet the minimum level recommended by the software develop company for this reasonable level. ⚓

CHAPTER 3 LNG DISPERSION ANALYSIS REPORT

Section 1 General

101. Overview

1. In the LNG dispersion analysis report, it can be helpful to evaluate the appropriateness of the location and height of the vent mast or other vent outlet based on the analysis results such as the flammable gas cloud developed by LNG discharges from vent outlets in normal or abnormal scenarios in system operation.

2. The person in charge of LNG dispersion analysis prepares a draft report by documenting the objectives, scope of work, input, assumptions and results in detail so that various stakeholders can easily understand.

(1) The person in charge of LNG dispersion analysis sends the draft report to the client and requests his review and comments on it.

(2) The client reviews the draft report and, if necessary, replies his comments to the person in charge of LNG dispersion analysis. In the case of no comments, the client informs that he agrees to the draft report as is.

3. Considering the comments from the client on the draft report, the person in charge of LNG dispersion analysis should complete the final report and then submit it to the client.

(1) If the client's comments are inconsistent with the final report, the comments should not be reflected on the final report of LNG dispersion analysis.

(2) If the client's comments are related to the errors of the draft report which are inconsistent with the final report, the comments can be reflected on the final report of LNG dispersion analysis.

(3) If the client's comments don't change the intent of the final report (e.g., apparent typing and/or grammatical errors, improper description on the results, writing styles, etc.), the comments can be reflected on the final report of LNG dispersion analysis.

Section 2 Contents

201. Essential contents

1. The contents of LNG dispersion analysis may vary depending on the target system design and operational concept, but the following should be provided sufficiently.

(1) Design and arrangement overview: This is a brief description of the design and arrangement related to the LNG dispersion analysis. All information and data regarding LNG dispersion into the atmosphere should be included in the report such as Process flow diagram(PFD), piping & instrument diagram(P&ID), calculation sheet for pressure relief valve and arrangement for vent mast. In the case of information and data that are difficult to included in the whole report, they can be omitted from the report by mentioning them in the form of references, and providing the material so that is available for viewing.

(2) Definition and assumption for input: Since they are the measure of the reliability degree for LNG dispersion analysis, definition and assumption for input such as scenario definition, selection of the model and software, monitoring point conditions, gas discharge conditions, environmental conditions and other conditions should be included in the report. However they may be different depending on the type of the model and software for LNG dispersion analysis.

(3) Result of dispersion analysis: As a result dispersion analysis, it can be helpful in evaluating the appropriateness of the location and height of the vent mast or other vent outlet, which is the goal of the LNG dispersion analysis. Hence, the results of dispersion analysis such as shape and extent of flammable gas cloud must be included in the report.

202. Report configuration

1. An example of the configuration for documenting the LNG dispersion analysis report is as follows.

(1) Summary: a summary of the main finding and conclusion for results

(2) Introduction: an overview of what led to the preparation of the LNG dispersion analysis report
(3) Abbreviations and references: descriptions of the abbreviations used in the LNG dispersion analysis report and a list of references
(4) Purpose and scope: purpose and scope of LNG dispersion analysis
(5) Target system overview: system design and arrangement information including the operational concept of the target system, etc.
(6) Methodology: description of the methodology for conducting LNG dispersion analysis for the target system, definition and assumption for input(scenario definition, selection of the model and software, monitoring point conditions, gas discharge conditions, environmental conditions and other conditions, etc)
(7) Result of dispersion analysis: LNG dispersion analysis result(if there are too many analysis results, they can be included as an attachment in the report)
(8) Conclusion: discussion on the main results on the LNG dispersion analysis ⚓

ANNEX 1 SAFETY ZONE ESTABLISHMENT (FOR LNG TRANSFER AND BUNKERING OPERATIONS)

101. Overview

1. In various circumstances, such as ship to ship, truck to ship and port to ship, if a leak occurs during the LNG transfer or bunkering operations, a flammable gas cloud is developed and then accidents such as explosion and fire may arise. In order to control these risks, the areas that can be affected by the flammable gas cloud from leakage must be designated in advance to reduce the foreseeable risks and measures that can be taken such as active monitoring activities and restrictions on surrounding movements must be carried out.

2. During LNG transfer or bunkering operations, areas that may be affected by leakage accidents should be set as hazardous zone, safety zone and security zone, and be monitored while operations. Hazardous zone is an area where a flammable gas cloud is expected to exist due to LNG leakage, and can be classified according to chapter 12 of IGF code and chapter 10 of IGC code. Safety zone is an area that only authorized and essential personnel are allowed to enter, and the ignition source control zone to prevent accidents such as fire/explosion. Here, essential personnel may be those required to perform or monitor the LNG transfer or bunkering operations. Security zone is an area established to monitor and control the activities, including the work not related to LNG transfer or bunkering operation and movement of the ships, vehicles and other personnel. It is not necessary to quantify the extent of security zone, but the safety zone should be defined for strict safety management.

3. Appropriate analysis and zone defining for the safety zone can minimize the possibility of an LNG leakage accident during LNG transfer or bunkering operation, and protect the personnel and property through physical separation by zone establishment.

102. Hazardous zone

1. Hazardous zone is an area in which a flammable or explosive gas cloud exists or is expected to exist that requires special precautions, such as controlling potential ignition sources in the manufacture, installation and operation of all components, including LNG transfer or bunkering operation systems. This zone can be established according to the IGF Code in the case of receiving vessels which is receiving LNG and the IGC Code in the case of bunkering vessels which is supplying LNG. Hazardous zone can be defined around the vent outlets, bunkering manifold valves, and other areas where the gas leakage may occur.

103. Safety zone

1. Safety zone can be defined as an area where there is a possibility of loss of life or damage on the properties by abnormally LNG leakage occur during LNG trafnser or bunkering operation. This area is a temporary zone only while LNG transfer or bunkering operation, and may include LNG receiving vessels, and bunkering vessels, and hoses or pipes interconnecting them, which can be usually wider area than hazardous zone. The purpose of safety zone is to minimize the potential for personnel injury and damage to equipment/infrastructure, which can be achieved through gas leak prevention and leak control, fire/explosion prevention according to ignition source management (explosion-proof certified electrical equipment and other work equipment, etc.), authorized personnel access, and protection for essential personnel by wearing PPE. Safety zone should always be controlled by the operational control manager, and relevant equipment and control facilities should be within the control range so that manager can make the necessary and proper order.

104. Security zone

1. Security zone is an area established to monitor and control the relevant activities to prevent accidents that may cause emergency situations due to operations/ships/facilities that are not related to LNG transfer or bunkering operations. This area is always larger than the safety zone as well as the hazardous zone. As safety zone, the security zone is an area that exists temporarily during LNG

transfer or bunkering operation, which can be established with consideration of all activities, including vessels passing through the sea or harbor where work takes place, loading/unloading work in the port, construction and maintenance work, vehicle operation, and movement of personnel.

105. Safety zone establishment

1. Safety zone can be established in two methods, through a deterministic approach and a probabilistic approach. The deterministic approach establishes a safety zone based on the distance to the lower combustion limit (LFL) for the maximum amount of LNG leakage, and the probabilistic approach establishes a safety zone through quantitative risk assessment (QRA). There are two ways to set up a safety zone, but this area must be established in consideration of the following, and not smaller area than these.

(1) Hazardous zone
(2) Requirements of the government regulatory requirements
(3) Requirements of the port/terminal
(4) Requirements of the national/international standard

2. Deterministic approach

(1) Safety zone can be established based on the size of flammable gas cloud developed by LNG leakage, a so-called ‘deterministic approach’.

(2) The size of flammable gas cloud can be defined as the range in which the LNG leak gas reaches the lower flammable limit(LFL) based on the results estimated from the dispersion analysis which can be analyzed utilizing the dispersion analysis model(Integral or CFD) and analysis software as well. When gas dispersion is greatly affected by structures with complicated shapes around areas with high potential for LNG leakage, it is necessary to conduct the dispersion analysis using CFD. For details, Section 3 in Chapter 1 of this guidelines can be referred.

(3) In order to establish the safety zone covering all potential leak scenarios, dispersion analysis should be conducted by selecting the worst-case scenario where the size of flammable gas cloud is maximum. It is necessary to consider the conditions under which the maximum amount of LNG can be leaked (LNG bunkering or transfer capacity, transfer pressure, temperature, etc.) and environmental conditions such as wind speed, wind direction, humidity, and temperature that can maximize the size of the flammable gas cloud. For details on selecting the worst-case scenario, refer to Section 3 in Chapter 2, Section 3 of this guidelines and following scenarios as well.

(A) Scenarios of residual LNG leakage in hoses/pipes trapped by emergency shut-off valves following collisions or mooring failures; Collision or mooring failure is warned in advance, and emergency shutdown(ESD) activation and ERS or detachable coupling are installed, but the remaining LNG in the hose/pipe is assumed to be leaked by one of the broken lines.

(B) Continuous LNG leak scenarios through broken instrument connections; It is assumed that LNG may leak without automatic detection by a gas detector, etc., emergency shutdown(ESD) is not activated, and the continuous LNG leaks through broken instrument connections while maintaining the normal pressure of the system.

(C) In addition to the above two scenarios, the maximum LNG leakage scenario identified through risk assessment such as HAZID.

3. Probabilistic approach

(1) Safety zone can be established through quantitative risk assessment(QRA) that quantifies the damage results from accidents by considering all potential accidents such as fire and explosion, including LNG leakage scenarios identified in HAZID, a so-called ‘probabilistic approach’. This approach can also be called as ‘risk-based approach’.

(2) In general, the safety zone established by this approach may have a smaller size than the zone defined through the deterministic approach. Also, theoretically, this approach can be estimated to be as large as or less than the size of the hazardous zone, but the safety zone should be established by following the minimum requirements specified by the relevant organization, such as the ports or authorities.

(3) This approach quantifies the risk of accidents by considering the leak conditions such as the size and frequency of the leakage, the location of the personnel, and the possibility of ignition. Therefore, it is possible to increase the understanding of the accident scenarios that contribute the most to risk, to identify the suitability of risk mitigation measures, and to optimize the

extent of the safety zone.

(4) Safety zone can be established by using the risk acceptance criteria that express individual risk(IR) for each different groups of personnel exposed to risk, as shown in Table 4 below which is utilized by major authorities.

Table 4 Example of risk acceptance criteria[ISO/TS 18683]

Group	Risk acceptance criteria	Remark
Operator for LNG transfer or bunkering	IR 〈 10^{-5}	Operator for LNG transfer or bunkering must be in the safety zone continuously while operation
Staff for port or terminal	IR 〈 $5x10^{-6}$	Staff for port or terminal must be outside the safety zone while LNG transfer or bunkering operation
3^{rd} parties who may be exposed to risk intermittently	IR contour 〈 $5x10^{-6}$	Third parties (passengers and other personnel visiting the workplace) must not be exposed to long-term risks.
General public who may be exposed to long-term risk	IR contour 〈 10^{-6}	General public(residential areas, schools, hospitals, etc.) should not be exposed to risks that are acceptable to third parties.

REFERENCE

1. D.M. Webber, 2002, On defining a safety criterion for flammable clouds, UK health & safety laboratory(HSL)
2. E.A. Bakkum, N.J. Duijm, 2005, Methods for the calculation of physical effects due to release of hazardous materials (liquids and gases) 'Yellow book', The netherlands organization of applied scientific research(TNO)
3. Frank P. Lees, 1996, Loss prevention in the process industries, Butterworth-Heinemann
4. International association of classification societies(IACS), 2016, Recommendations no. 142 LNG bunkering guidelines
5. The international safety guide for oil tankers and terminals(ISGOTT), 2020, International safety guide for oil tankers and terminals, Witherby publishing group
6. International organization for standardization(ISO) 18683, 2015, Guidelines for systems and installations for supply of LNG as fuel to ships
7. International organization for standardization(ISO) 20519, 2021, Ships and marine techonology - Specification for bunkering of liquefied natural gas fuelled vessels
8. Korea meteorological administration(KMA) website, 2022, number of days with specified value inte(wind rose), https://data.kma.go.kr
9. Korean register(KR), 2022, Guidance relating to the rules for the classification of ships using low-flashpoint fuels
10. Korean register(KR), 2022, Rules for the classification of ships using low-flashpoint fuels
11. M.J. Ivings, S.E. Gant, S.F Jagger, C.J. Lea, J.R Stewart and D.M. Webber, Evaluating vapor dispersion models for safety analysis of LNG facilities, UK health & safety laboratory(HSL)
12. National institute for occupational safety & health(NIOSH), 2022, Immediately dangerous to life or health (IDLH) values, https://www.cdc.gov/niosh/idlh/
13. Norwegian university of Science and Technology(NTNU), 2014, LNG bunkering operations
14. Occupational safety and health administration(OSHA), 2022, Permissible exposure limits - annotated tables, https://www.osha.gov/annotated-pels
15. R.E. Britter, J. McQuaid, 1988, Workbook on the dispersion of dense gases, UK health & safety executive(HSE)
16. S.E. Gant, V.D. Narasimhamurthy, T. Skjold, D. Jamois, C. Proust, 2014, Evaluation of multi-phase atmospheric dispersion models for application to carbon capture and storage, Journal of loss prevention in the process industries 32, 286-298
17. The society for gas as a marine fuel(SGMF), 2017, Safety guidelines
18. The society for gas as a marine fuel(SGMF), 2018, Recommendations of controlled zones during LNG bunkering

⚓

GUIDELINES FOR LIQUEFIED NATURAL GAS DISPERSION ANALYSIS

Published by
KR
36, Myeongji ocean city 9-ro, Gangseo-gu,
BUSAN, KOREA
TEL : +82 70 8799 7114
FAX : +82 70 8799 8999
Website : http://www.krs.co.kr