Risk Assessment and Application of Port Liquefied Natural Gas Trucks Bunkering Based on Hazard Identification and Computational Fluid Dynamics

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Abstract—In order to safely and orderly promote the application of LNG as a clean energy for inland river ships, the paper takes a port truck to bunker a 2000 tons LNG power bulk carrier for example, carrying out a qualitative risk assessment based on HAZID method, putting forward risk prevention and control measures, and using FLACS software to get CFD accident consequence quantitative calculation. The analysis shows that the overall risk is controllable under certain measures. It is the first time that this method has been applied to the risk assessment of Trucks Bunkering.

1. Introduction

Promoting the use of liquefied natural gas (LNG) for clean energy on ships is an important measure to thoroughly implement General Secretary Xi Jinping's thought on ecological civilization, resolutely win the battle against blue sky and fight the battle against pollution. In order to accelerate the construction of ecological civilization and pollution prevention and control in China[1], the CPC Central Committee and the State Council has formulated the "about strengthening ecological environment protection Resolutely play pollution prevention and control of the opinions of the battle ", "win the sky battle action plan for three years and a series of policy, clearly put forward" active and control ship pollution and ship transformation and upgrading, and promote the use of new energy and clean energy such as natural gas ships, Strengthen the demonstration and application of green ships "recently. Up to now, there are more than 310 LNG powered ships in China, and Guangdong plans to build or renovate 350 ships by the end of this year. The demand for LNG bunkering is increasing day by day.

The construction of LNG bunkering system is the core link to promote the application of LNG in ships. In order to ensure that new and rebuilt ships have gas to fill, it is an important measure to ensure reliable bunkering of LNG by tank truck before shore-based and barging bunkering stations are built to meet the gas needs of ships. LNG is flammable and explosive dangerous goods, and bunker safety is an important basis to promote the sustainable development of ships using LNG clean energy. This project is in accordance with the Notice issued by Maritime Safety Administration of the People's Republic of China on the revision and issuance of Safety Supervision and Management Measures for Floating LIiquefied Natural Gas Bunkering Operation (Haiweifang (2021) No. 148) and Technical Requirements for Bunkering Operation of Natural Gas Fuel Powered Ship Tank Truck (JT/T) On the basis of relevant laws and regulations and standards, carry out qualitative and quantitative analysis of tank car bunkering risk, so as to ensure the safety of LNG fuel bunkering operation of LNG trucks at port[2][3][4].

2. Evaluation Methods

Hazard Identification (HAZID) method is used for qualitative analysis. HAZID identifies, analyzes and evaluates potential safety hazards and their consequences in the process of operation by using the brainstorming method combined with the corresponding checklist. According to the analysis results, measures are proposed to control the risk level and failure scenario input is provided for Quantitative risk assessment (QRA)[5-6]. The specific work flow of HAZID is shown in Fig.1.

The Computational Fluid Dynamics (CFD) software FLACS (Flame Accelaratition Simulatation) was used for quantitative analysis. The software was developed with funding and guidance from the relevant oil companies BP, Conocophillips, ExxonMobil and Statoil, as well as three national legislative bodies: the Health and Safety Executive (HSE) of the United Kingdom, the Norwegian Petroleum Agency (NPD) and the German Ministry of Research and

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Technology (BMFT). FLACS is the designated explosion risk assessment tool for major oil and gas companies. FLACS can meet the risk assessment requirements of relevant international standards in the oil and gas industry (such as ISO13702, NorSOKZ-013, ISO/DIS 19901-3). For LNG, FLACS is licensed by the U.S. department of transportation's (DOT) pipeline and dangerous goods safety administration (PHMSA) to simulate the diffusion of LNG vapor clouds under federal regulation 49 CFR193.2059.

2.1. Bunkering Object

This project takes 2000 tons of pure natural aerodynamic bulk cargo as the object, as shown in Fig.2(a), and the main parameters are shown in Table 1. The ship's LNG Marine fuel tank is 30m³, and the single bunkering capacity is about 80% of the tank capacity, i.e. 24m³.

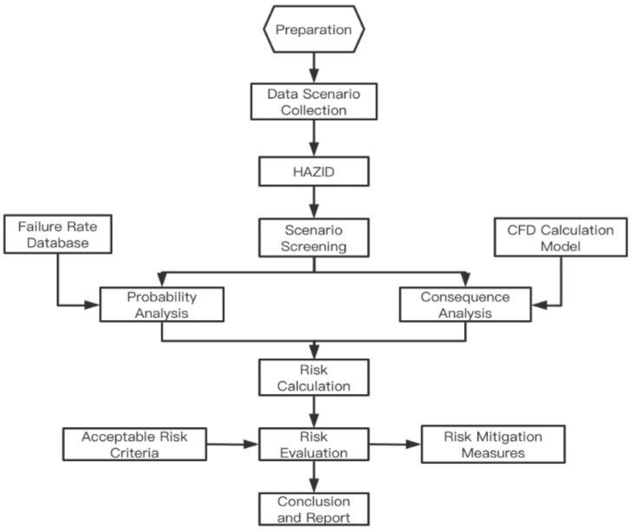

Figure 1. Risk Evaluation Process

3. Application Case

Table 1. 2000 tons LNG powered ship parameters

Ship Type		Total Length	Width	Depth	Navigation Zone	LNG Fuel Tank			Bunkering Liquid Pipe Flange Spesification	Bunkering Gas Pipe Flange Spesification
						Volume	Working Pressure	Design Pressure		
Bulk Cargo Ship	2000 Ton	59.9m	15.8m	4.5m	Inland River A Level	30m³	0.7～0.9MPa	1.2 MPa	DN50	DN50

3.1. LNG Bunkering Facility

The 55m³ capacity truck used in the LNG bunkering facility of this project, as shown in Fig. 2(b), realizes the LNG fuel bunkering of ships through the port integrated skid.

Figure 2. (a)LNG Powered ship; (b)LNG Truck

3.2. Bunkering Medium

The bunkering medium of this project is LNG fuel, and its physical characteristics are shown in Table 2.

Table 2. LNG Physical Property Parameters

Average Molecular Weight	17.3
Main Ingredients	93.6% methane (CH4) approximately, 4.12% ethane (C2H6) approximately
Gasification Temperature	-163℃ （Ordinary Pressure）
Liquid Density	447 Kg/m approximately
Gas Density	0.772 Kg/Nm3 （15.5℃）
Gas/Liquid Volume Ratio	612.5：1（15.5℃）
Fire Point	650℃
Average Molecular Weight	17.3

3.3. Bunkering Operation Area Layout

The truck of this project carries out LNG bunkering operation of purely natural gas-powered ships in a port, as shown in Fig.3.

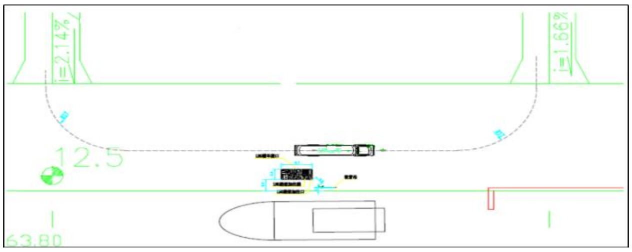

Figure 3. Schematic diagram of bunkering operation area in a port

4. Risk Analysis

4.1. Qualitative Risk

4.1.1 Risk Assessment Node Division

This project adopts truck to bunker LNG fuel for natural gas-powered ships. HAZID risk analysis is divided into three and two nodes according to the operation process. Node 1: truck- integrated skid and truck hose joint, mainly for truck, integrated skid and its connection hose joint risk identification; Node 2: Integrated skid and truck hose joint - ship bunkering station interface, mainly for integrated skid, LNG bunkering station and its connection hose joint risk identification.

4.1.2 Risk Matrix

The risk matrix is a way of combining qualitative or semi-quantitative grading of consequences with the likelihood of producing a certain level of risk or risk level. The risk matrix can be customized or graded according to relevant standards. This report refers to the recommended guidance document for risk assessment as required by IACS REC.146 IGF regulation and ISO 17776:2000 for the oil and gas industry. Offshore mining installations - Risk matrices in the methodological and technical guidelines for hazard identification and risk assessment as a basis for grading identified risk sources. The risk matrix is shown in Fig. 4.

Consequences	**C3.Multiple Deaths**	Medium	Medium	Medium	High	High
	C2.Single Death or Multiple Injuries	Low	Medium	Medium	Medium	High
	C1.Multiple Injuries	Low	Low	Low	Medium	Medium
		L1 ＜10E-6/y＜ 1/40000	**L2** 10E-6～10E-5/y, 1/40000～1/4000	**L3** 10E-5～10E-4/y, 1/4000～1/400	**L4** 10E-4～10E-3/y, 1/400～1/40）	**L5** ＞10E-3/ ＞1/40
		Probability (probability of occurrence per year, 1 occurrence for N ships)				

Figure 4. Risk Matrix Chart

4.1.3 Analysis Result

HAZID analysis method was used to conduct qualitative risk assessment for the two nodes divided, and some analysis results are shown in Table 3.

Table 3. HAZID Risk Analysis results of LNG Bunkering by Truck for Natural Gas-Powered Ship (Part)

Order and Categary	Hazard Source Guide Word	Reason	Consequence	Existing Safety Measures	C	L	R	Suggestive Measures	Responsible Party
1.1 Truck and Unloading Hose	1.1.1 Layout and Environment	1. The truck moved unexpectedly during bunkering.	1. Hose damage, resulting in LNG/NG leakage, low temperature injury or fire; 2. Collisions between trucks damage vehicles and pipelines.	1. Before unloading the liquid, make sure the truck engine is off, the car key is unplugged and the handbrake is pulled up; place a triangle of wood at both ends of the wheels. 2. In the process of unloading liquid, forbid idle people to stay and watch, and forbid the driver to turn on the vehicle power.	C2	L3	Medium	1. Set truck limit device, or equivalent fixed device.	Bunker service party
		2. Interference by other irrelevant	1. Accidental collision leads to damage of	1. Set up waiting area for trucks, and set up a warning area around the waiting	C2	L1	Low	1. Set warning signs at the entrance and exit of the fence to remind	Bunker service party

Order and Categary	Hazard Source Guide Word	Reason	Consequence	Existing Safety Measures	C	L	R	Suggestive Measures	Responsible Party
		vehicles and personnel.	unloading hose, resulting in LNG/NG leakage, low temperature injury or fire; 2. Open flame may cause fire.	area, non-ruck operators are forbidden to enter the warning area. 2. Set up safety warnings and warning signs in the LNG unloading area.				other vehicles and personnel that LNG bunkering operations are in progress during refueling. 2. Set warning signs on the fence.	
		3. Fire outside the dump area.	1. Fire in unloading area.	1. The unloading area has been equipped with fire-fighting equipment in accordance with the Design Code for Inland LNG Bunkering Terminal (JTS 196-11-2016).	C 2	L 1	Low	1. No piles of flammable and explosive goods or items within the appropriate range, and quantify the size of the range.	Bunker service party
		4. Electrostatic sparks are generated in the unloading area by personnel and trucks.	1. A fire occurs when flammable gas is present.	1. LNG tankers are connected to electrostatic grounding wires. 2. All personnel entering the guarded area wear anti-static clothes and shoes.	C 1	L 2	Low	1. Set up personnel elimination static device at the entrance of the fence.	Bunker service party
2.1 Loading Skid and Bunkering Hose	2.1.1 Layout and Environment	1. The combustible gas probe is improperly positioned.	1. No leak detected.	Not seen.	C 2	L 3	Medium	1. Clearly define the location of the combustible gas probe of the loading sled, and suggest to arrange the combustible gas probe near the joint.	Bunker service party
	2.1.2 Attatchment	5. In the process of bunkering, weather changes (e.g. extreme weather).	1. Affect bunkering operation.	1. Stop bunkering operations immediately during high intensity lightning and frequent lightning strikes. 2. Stop bunkering operation immediately during high intensity lightning, frequent lightning strikes and unexpected events inside or outside the refueling station	C 1	L 3	Low	1. Define emergency procedures for extreme weather in the bunkering program.	Bunker service party

4.2. Quantitative Analysis

4.2.1 Calculation Parameter

In this project, the diameter of the liquid and gas phase pipes of the bunkering hose is DN50, the bunkering rate is 7m/s, the bunkering pressure is 0.7mpa, and the leakage time is 60s, including 30s leakage detection time and 30s equipment shutdown time.

According to the meteorological observation data of the port from 1994 to 2013, the annual average wind speed is 2.1m/s, the annual average temperature is 22.64℃, and the average relative humidity is 75. The average annual dominant wind is NE wind, with wind frequency accounting for 16.3%; the secondary dominant wind is NNE wind, with wind frequency accounting for 11.1%; the average annual static wind frequency in this region is 11.9%, as shown in Table 4.

Table 4. Annual Wind Frequency of Port Location (%)

Wind Direction	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**C**	**Dominant Wind Direction**
Wind Frequency	4.8	11.1	16.3	9.8	6.9	5.6	4.6	4.4	4.5	3.5	3.0	2.2	2.2	2.4	3.7	2.9	11.9	NE

4.2.2 Acceptance Criteria

According to GB/T 20368 "Liquefied Natural Gas (LNG) Production, Storage and Shipment", "Guideline for Quantitative Risk Assessment of Oil and Gas" and

"Guideline for LNG Bunkering Operation", the volume concentration of combustible gas in air is 50% of the lower limit of flammability (2.5% for methane) as the diffusion boundary.

4.2.3 FLACS Model Establishment

The overall model of port bunkering area, tank and bunkering skid model, 2000 tons LNG-powered ship model and LNG hose boom model constructed by FLACS software are shown in Fig.5 (a) (b) , Fig. 6 (a) (b) respectively.

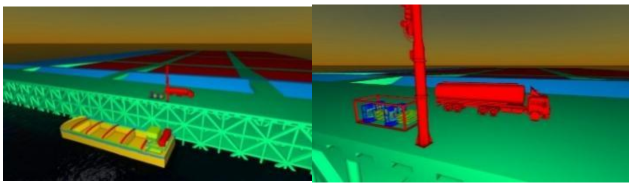

Figure 5. (a) CFD Calculation Model; (b)Truck and bunkering Skid Model

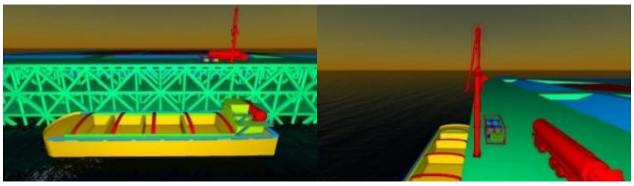

Figure 6. (a)2000 tons LNG Storage Ship Model; (b)Hose Boom Model

4.3. Scenario Analysis and Results

Calculate and consider three scenarios: full hole leakage, half hole leakage and 1/10-hole leakage.

4.3.1 Scenario 1: 1/10-hole leakage

According to the simulation calculation, the leakage result of 1/10 hole of the bunkering hose is about 4m in the range of combustible concentration (0.025-0.15), as shown in Fig.7(a).

4.3.2 Scenario 2: half hole leakage

According to the simulation calculation, the half hole leakage result of the bunkering hose is about 30m in the range of combustible concentration (0.025-0.15), as shown in Fig. 7(b).

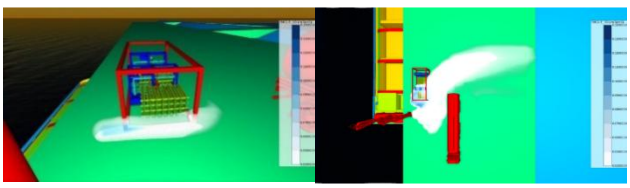

Figure 7. (a) Calculation Result of 1/10 Hole of Bunkering Hose; (b)Calculation Result of Half Hole of Bunkering Hose

4.3.3 Scenario 3: full hole leakage

According to the simulation calculation, the leakage result of the full hole of the bunkering hose is about 80m in the range of combustible concentration (0.025-0.15), as shown in Fig.8.

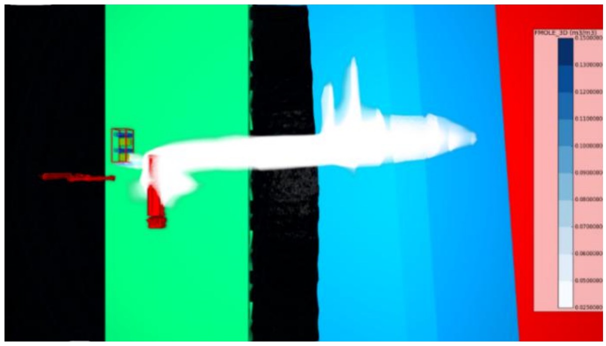

Figure 8. Calculation Result of Full Hole of Bunkering Hose

5. Conclusions

According to the results of qualitative and quantitative analysis, the evaluation conclusions are as follows:

1) Truck- integrated pry with truck hose joint. The main risk lies in the bunkering process: first, the truck moves unexpectedly, which will lead to hose damage, and then lead to LNG/NG leakage, low temperature injury or fire. It is suggested to control the risk by confirming that the truck engine flays off before discharging liquid, pulling up the key and pulling up the handbrake, placing triangular wood at both ends of the wheel and setting the truck limit device or equivalent fixing device, etc. Secondly, the joint between the unloading hose and the truck or the unloading pry leaks, resulting in low temperature injury, and may cause fire in case of open fire. It is suggested to strictly require operators to wear antifreeze gloves, set up restricted areas according to JT1319-2020 "Refueling Requirements for Natural Gas Fuel Powered Ship Truck" and combined with quantitative analysis results, and strictly prohibit ignition sources within the restricted areas to control risks.

2) Integrated pry and truck hose joint - ship bunkering station interface. The main risk lies in the bunkering process: firstly, due to the rolling of the ship, the joint between the ship's bunkering hose and the loading skid fails, and LNG leaks occur. It is suggested to control the risk by strengthening the ship's mooring design and paying more attention to the ship's mooring status during bunkering. The second risk occurs at valve parts and joint leakage, and open fire may cause a fire. It is recommended to check the regular inspection and test records of valves and joints before bunkering to ensure that the valves and joints are in good working condition to control risks.

3) The leakage results of 1/10 hole of the filling hose show that the distance of vapor cloud diffusion along the wharf is about 4m within the range of combustible concentration. In the case of half-hole and full-hole leakage,

the distance of combustible vapor cloud diffusion along the wharf formed in the port operation area is about 30m and 80m respectively. Considering the hose length and number of valves, and the bunkering facility is equipped with a valve, hose and half diameter and the diameter of burst probability is very low, according to the accident database and the relevant international risk assessment practice, the project implementation process of risk prevention and control measures, and set up around the mouth bunkering is not less than 25 m range of restricted areas, A warning area of not less than 50 meters can control the risk within an acceptable range.

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