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Safety Assessment of LNG Terminal Focused on the Consequence Analysis of LNG Spills

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Abstract

The consumption of natural gas worldwide will almost double by 2030 and the rate of increase is 2.3% per year. Demand is projected to grow most rapidly in Africa, Latin America and developing Asia. Meanwhile, the percentage of the global demand on primary energy will increase from 21% in 2002 to 25% 2030. Gas-resources will increase in global demand and proven reserves are now equal to about 66 years of production at current rates. Cumulative investment needs for gas-supply infrastructures to 2030 will amount to $2.7trillion, or about $100 billion per year. Therefore, LNG is and has been an important, reliable part of the world energy infrastructure for almost 40 years.

To understand safety issues and hazard characteristics in LNG terminals, we find out possible accidents scenarios come from historical data and incident-tree analysis for LNG release. Then, the resultant accident scenarios have been modelled with varying tank-capacities and hole-sizes; the consequence analysis has been performed to discuss relevant safety issues.

Keywords: LNG Terminal, LNG Spill, Consequence Analysis, Safety Assessment

1. Introduction

In the Pacific Rim alone, there are more than 30 LNG re-gasification terminals. More than several tens of new terminals are under consideration, and are likely to be built within the next ten years. Needless to say, the demand is increasing, and at the present rate of approximately 2.3% per year it will double by 2030. As the demand and consumption of LNG increase, the risk increases which in turn necessitates more research to improve the safety. In fact, the hazards of importing LNG have been studied intensively over the past years. Many focused on the pool development and the effect distance in the case of spill on the water; a few were devoted to the safety issues and hazard characteristics in the tanks and/or terminals.

In this paper, we analyze the safety issues and the hazards in LNG terminals. First, the possible incident scenarios of both accidental and intentional release are identified. Then, credible, and worst case release and fire are simulated to calculate the impact of LNG spills.

2. LNG hazards and release scenarios

2.1. LNG Hazards

Based on past accidents and experiments, researchers and field-experts recognize the following hazards in LNG: explosion, vapour clouds (fire), freezing liquid, rapid phase transition (RPT), rollover—occurs when a stratified layer within storage tank breaks down and allows the relatively hot LNG from the lower parts of the tank to come to the surface, liberating large quantities of vapour (Cleaver and Johnson, 2007, p. 429-438). Among the listed, vapour cloud dispersion and fire are considered as the principal hazards in the case of LNG releases (Havens and Spicer, 2007, p. 439-443). In fact, the regulatory safeguards, impoundment and separation distance, for LNG terminals are set by the government to provide the protection against this hazard—thermal radiation from the dispersed vapour clouds. In this sense, calculating the LFL distance is the key safety issue for decision-making (Pitblado, and Baik, 2006, p. 148-154), and in this paper we also adopt the LFL distance and thermal radiation from the vapour cloud fire as the basis for the consequence analysis.

2.2. Incident scenarios for spill/releases

Throughout the past 60 years, a few LNG accidents occurred both on and offshore. In 1965 there was LNG spill during the transfer operation, and resulted in a pool fire that took several lives in the Canvey Island, UK. Recently, a large fire in liquefaction facility of Skkida, Algeria was followed by a catastrophic explosion that took away 27 lives and left 74 wounded.

Accidents in LNG terminals can be either operational or non-operational. Operational accidents include over-pressure, igniting sparks, collision (ship-to-ship), ramming (ship-to-fixed object), and grounding. In contrast, earthquakes, hurricanes, aircraft crashes, adjacent fires, sabotage and terror lead to the non-operational accidents. Generally speaking, the operational accidents are more probable but pose fewer hazards; they have been the target for the safety measures in the past but with the advent of global terrorism, the non-operational types have now become more relevant.

Either operational or non-operational, LNG spill/releases occur in storage vessels or valves and pipelines. Of the two, the vessels pose greater risk for they contain greater volume in the limited area. In fact, most risk assessment and effect distance calculations for LNG spill are concerned with the releases from the storage vessels. Accordingly, we also focus our analysis on the releases from the vessels. Then, the application of Fault Trees Analysis based on the past accident data can generate the possible leak/release scenarios as summarized in Fig. 1.

Fault Trees Analysis is one of the numerous techniques employed in risk assessment when generating the possible causes for failure. It uses logical reasoning and past failure data in listing the lower level events that are responsible for the higher level event/failure. In this study, the highest level event is set as the LNG release from the vessel; this can only take place when there’s a rupture or leakage. Thus these two events make up the next level events. At the lower level, over pressure, physical attack and/or temperature increase are identified as the causes for rupture or leakage. The following 6 lowest level events have been generated with the past accident data.

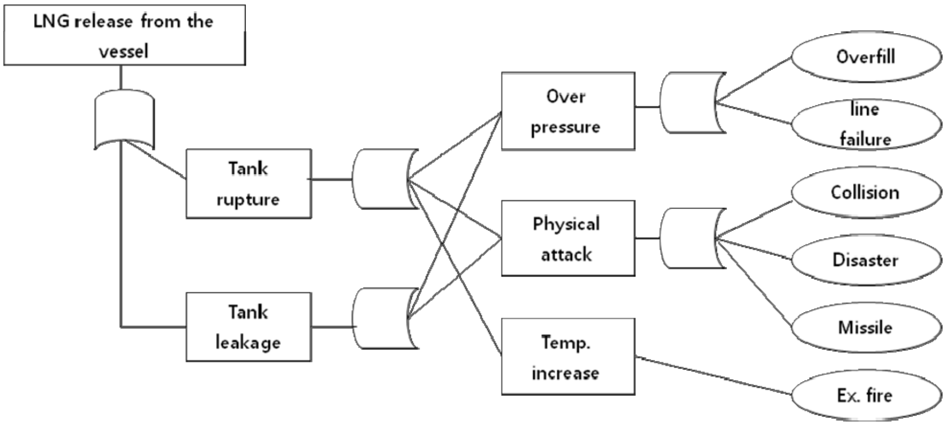

Figure 1. Release scenarios for LNG storage vessels in on-shore terminals

The scenarios described above do not cover all possible events that can lead to tank rupture or leakage in the LNG terminals. However, they do cover the most likely causes that will result in disastrous accidents. Overfill, collision, external fire, and line failure—these initial events are responsible for more than two thirds of the major accidents reported to date. Missiles are of concern when the terrorists become a considerable threat, and natural disasters such as hurricanes and earthquakes should be taken into account for they can also result in disastrous accidents.

3. Modeling and methodology

3.1. Modeling approach

There are several models and/or codes available for simulating LNG releases. Physical models using discharge rates and/or extending Bernoulli's relationships are used in modeling discharge of LNG. Numerous models have been suggested in modeling the dispersion phenomena, from simple Gaussian models to computational fluid dynamics codes. Among the proposed, many recommend that CFD provides the most accurate description of the LNG vapor cloud dispersion (Koopman, 2007, p. 412-428). In terms of the consequence analysis, however, PHAST has also been recognized as valid (Pitblado and et al., 2004).

PHAST is used by more than 600 organizations as consequence codes. In simulating the dispersion, it uses a proprietary dispersion model called the unified dispersion model (UDM). UDM was formulated as a similarity model in which concentration and other variables are assumed to have a predefined profile. It also assumes generalized Gaussian profiles. Entrainment, spreading etc. is calculated from a numerical (Runge-Kutta-Milne) solution to differential equations for mass, momentum and heat transfer between the cloud and its environment.

3.2. Simulation method

Numerous variables and/or conditions need to be defined in order to simulate the release of LNG by PHAST. They include the weather conditions, tank size and storage conditions, chemical compounds contained, and accident types and conditions such as the hole-size and height in case of release. In the following paragraphs, values we assigned for these variables/conditions and the grounds for the assignment are explained.

3.2.1. LNG composition

The literature reports that the LNG composition of methane varies from 80~97% (Woodward, 2007, p. 478-487). Here, we assume 90% to assume the average value; the remaining components consist of ethane (8.7%), propane (0.4%), n-butane (0.6%), and n-pentane (0.3%).

3.2.2. LNG storage vessels

LNG is typically stored in double-walled tanks at atmospheric pressure. The outer tank is generally made of carbon steel while the inner tank is made of materials suitable for cryogenic service such as pre-stressed concrete and aluminum. The temperature is maintained around -160 degrees Celsius, which we adopted in the simulation; the size varies from 125,000 ~ 240,000 m^3 (Pitblado, and Baik, 2006, p.148-154).

3.2.3. Scenario representation

In calculating consequences of LNG releases from various scenarios, two variables are manipulated—the hole, and storage vessel size. These two variables are mainly responsible for the extent and severity of the LNG vapor cloud fires. They are also the variables that may differ significantly from one scenario to the other, except the location of the hole and weather conditions; however, these two are assumed to be identical for all the proposed scenarios since they can be treated as random variables.

From accident scenarios of Fig. 1, we have built 6 model-cases for release consequence analysis. They vary in the hole and storage vessel size as shown in Table 1. The cause “operation” stand for operational accidents, including overfill, external fire, line failure and collision of Fig. 1. The maximum credible hole-size for this root cause has been assigned according to the Hazid session that consists of roughly 20 industry specialists (Pitblado, and Baik, 2006, p.148-154). “Missile” represents the likely means of damage by the terrorists; “disaster” refers to events that can lead to the worst case, with the hole-size of 5m assigned by numerous authors (Havens, et al., 2004, p. 400-412).

Table 1. LNG terminal tank release scenarios

	Case1	**Case2**	**Case3**	**Case4**	**Case5**	**Case6**
Cause	Operation	Operation	Missile	Missile	Disaster	Disaster
Temp.	-160°C	-160°C	-160°C	-160°C	-160°C	-160°C
Tank size	125000 m^3	240000 m^3	125000 m^3	240000 m^3	125000 m^3	240000 m^3
Hole size	0.75 m	0.75 m	1.5 m	1.5 m	5.0 m	5.0 m
Weather	1.5/F	1.5/F	1.5/F	1.5/F	1.5/F	1.5/F

4. Consequence analysis

The simulation results by PHAST (version 6.5.3) are presented in Table 2. For all 6 scenarios (or cases as they appear on the top row of Table 2) the weather condition has been set as 1.5/F, with no impoundment/dikes; the assigned weather condition is the one that leads to the farthest dispersion. As mentioned before, the focus is on the LFL distance, and the distance by which the pool fire radiation intensity reduces to 5kW/m^2. The LFL for pure methane gas is 5%. For the mixture with the composition described earlier in 3.2.1, the LFL can be estimated using the Le Chatelier equation[1]– 4.6%.

$$LFL_{mix} = 1/[\sum (y_i/LFL_i)]$$

Table 2. Results of consequence analysis for each incident/release scenario

	Case1	**Case2**	**Case3**	**Case4**	**Case5**	**Case6**
Cause	Operation	Operation	Missile	Missile	Disaster	Disaster
Tank size	125000 m^3	240000 m^3	125000 m^3	240000 m^3	125000 m^3	240000 m^3
Hole size	0.75 m	0.75 m	1.5 m	1.5 m	5.0 m	5.0 m
LFL dis.	1252 m	1252 m	2650 m	2650 m	6365 m	8796 m
Early fire	167 m	167 m	291 m	291 m	769 m	769 m
Late fire	440 m	440 m	816 m	816 m	1380 m	2409 m

From Table 2, three immediate observations can be made. First, the LFL distance increases as the hole-size increases, with all other variables remaining constant. At the worst case scenario, the released vapour is flammable at the distance 8.8km downwind

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[1] H. Le Chatelier, “Estimation of Firedamp by Flammability Limits”, Ann. Mines, vol. 19, ser. 8, 891, pp. 388~395

from the origin. Second, the pool fire effect distance (both early and late) is shorter than the LFL distance. On the average, the early pool fire effect distance is about 1/8 of the LFL distance while the ratio increases to roughly 1/3 in the case of late pool fire. Lastly, the tank size does not influence the effect distance (either LFL or pool fire) unless the hole size becomes significantly large: only sufficiently large holes can result in a discharge rate fast enough to make difference. In this simulation, the difference was only observed when the hole was 5.0 m big.

Relevant safety issues can be checked by comparing the simulation results with the current practice in LNG terminals. A recently built LNG terminal in Kwang-Yang, South Korea is roughly 300,000m^2 large. This means a width of 500~600m. Clearly, it is wide enough to guarantee safety for the people and property outside the terminal in case a casual operational accident takes place: the LFL distance is greater than the boundary width, but in reality it is extremely unlikely that the released vapour reaches the maximum distance without ignition. Thus the late pool fire is chosen as the pertinent measure in evaluating the safety. In this sense, the new terminal is not safe enough in case of less frequent, but more severe accident scenarios such as terrorism or natural disaster. The simulation results indicate the effect distance of more than 2.4 km at worst. As these scenarios have become more relevant nowadays, more investment needs to be considered in terms of the safety-guaranteeing terminal dimensions.

Due to the huge expense and difficulty of having experimental data of LNG release in the scale described in the scenarios, there is no accurate estimate for the errors involved in the simulation. However, there do exist literary works that suggest the range of error for the simulation outcome. Among them, one directly discussed the % error involved in simulating LNG release with PHAST in comparison with other well known codes, and accordingly the results differ by -50% to 80% for PHAST (Pitblado and Baik, 2006, p. 148-154).

5. Conclusion

LNG (on-shore) terminal consequence analysis has been performed with respect to various release scenarios. Historical accident records and FTA technique have been employed in building the accident scenarios and resulted in 6 cases with different hole sizes—0.75m, 1.5m, and 5.0m. Then, each case was simulated by PHAST, and LFL, early and late pool fire effect distances have been estimated. Comparison of the simulation results with the current practice for constructing LNG onshore terminals lead to the following conclusions. First, the current dimensions guarantee safety to the neighbourhood in case of operational accidents. Second, for all credible spills, including terrorist attacks and natural disasters, the danger area extends to 2.4km downwind from the point of release; this is much wider than the current dimensions of the facility and therefore more safeguards should be considered in providing safety against these types of accidents. Lastly, there is much difference between the effect distance in case of early and late fire. Since the latter is larger by more than twice, it is suggested that the LNG terminal prepare safeguards prioritized in preventing fire.

Additional work is required in validating the simulation results and hence building more accurate models for LNG releases. CFD models have been acknowledged by numerous researchers and field-experts as the most accurate; however, they too have not been validated with large-scale experiments. The greater the accuracy of the simulation results, the less burden the managerial decision making needs to incorporate due to the uncertainty. In addition, more work is necessary in building an effective fire prevention measure. The thermal radiation damage due to released LNG pool fire has been demonstrated to be the principal source for the hazard, and thus is the primary target for loss prevention.

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