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Simplified Method to Define the Cryogenic Spill Hazard in LNG Liquefaction Facility

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In these years, risk mitigation measures against the cryogenic spill hazard become one of the critical factors to ensure the level of safety in cryogenic liquid handling process plant, such as LNG liquefaction facility. The cryogenic risk mitigation can be achieved by spill control, welding connection instead of flange connection, and cryogenic spill protection insulation on the structure and equipment, etc. In the LNG liquefaction facility, cryogenic spill protection insulation is commonly applied for the critical area in combination with other risk mitigation measures. On the other hand, there is no recognized standard approach to define the extent of area which cryogenic spill protection insulation applied even if the installation of cryogenic spill protection insulation is high cost and have difficulties in construction phase.
This paper proposes the simplified method to define the extent of cryogenic spill hazard area supported by the experimental test and simulation. For the less congested area of the facility, point source approach is applied. Leak frequency is calculated per flange and credible leak hole size is defined. Then, the extent of brittle fracture hazard area due to cryogenic hydrocarbon spill is decided from each flange. For the congested area, generic source approach is applied. In these areas, all leak sources are counted around the equipment to define the leak frequency, and credible leak hole size is defined. Then, the extent of brittle fracture hazard area is defined from the equipment. The cryogenic spill hazard area is considered as the extent of the LNG liquid droplet travel distance because the cryogenic liquid contact on the structure will cause the brittle fracture hazard (Wet condition on the surface on the structure cause the significant temperature drop). Simulation and Experimental Test are conducted to determine the extent of hazard area against the leak hole size.

1. Introduction

Passive Fire Protection (PFP) insulation is widely applied in the oil and gas industry for many years and the design criteria are indicated in international standards (e.g., API 2218, Fireproofing Practices in Petroleum and Petrochemical Processing Plant), company standards, etc. On the other hand, the modularized onshore LNG projects and floating LNG projects are increased, and risk mitigation for cryogenic spill hazard to steel structures (i.e., brittle fracture) becomes one of the major interests in the industry in addition to the passive fire protection against the fire event. Risk mitigation measures for the cryogenic spill hazard to steel structures are 1) reducing leak sources (avoiding small bore connections and applying welding connection), and 2) protecting steel structures by active or passive ways (water spray or cryogenic spill protection insulation). However, due to the limitation of applying welding connection from operation/maintenance view, it is known that the measure reducing leak sources is not concrete solution. Then, because the passive type protection is inherently safer than active type protection, cryogenic spill protection insulation is considered as feasible and practicable solution in many projects.
However, the approach of determining 1) Phase of spilled cryogenic hydrocarbon on the steel structure (i.e., liquid fraction) which affect the thickness of cryogenic spill protection (CSP) insulation, and 2) Extent of brittle fracture hazard area due to cryogenic hydrocarbon spill, has not been standardized as an international design standard. Currently, these design conditions are decided differently project by project. In many cases, the phase of spilled cryogenic hydrocarbon is assumed as liquid phase to determine the insulation thickness, and

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the liquid nitrogen immersion test is considered as conservative approach for the vertical column because the horizontal cryogenic jet spray will affect one side of structure, causing less heat reduction on the affected steel.
The extent of brittle fracture hazard area is commonly defined by risk analysis, or deterministic approach. For the risk analysis, completed engineering information (such as P&ID, piping layout) is required to conduct the analysis. Therefore, the extent of brittle fracture hazard area become available in the later stage of the engineering, despite the extent of the brittle fracture hazard area is required to proceed detailed engineering. In addition, the method of risk analysis has not been well established yet in view of cryogenic spill dispersion phenomenon and brittle fracture mechanism. For the deterministic approach, extent of brittle fracture hazard area will be defined in the early engineering phase. However it will be less technically justified because the criteria used in the method does not have a enough technical background.
In order to establish the simplified and practical engineering approach, the simulations and experimental test are conducted and reported by the Authors (Hiroya et al., 2016), defining the extent of brittle fracture hazard area for the specified leak hole size and process fluid condition. To apply the proposed simulations to define the extent of brittle fracture hazard area, the leak location, the leak hole size, process fluid and pressure shall be defined prior to conduct the simulations. In the LNG liquefaction facility, there are many potential leak points (flanges, seals, etc.), which is causing the difficulties to define the condition of the simulation to finalizing the extent of the hazard area.
This paper proposes the appropriate simplified method to define Cryogenic Spill Hazard Area in LNG Liquefaction Facility, as defining the leak location and credible leak hole size based on the actual leak scenario considered in the safety study and experience, which is leading defining the extent of hazard area simply and adequately in the early phase of the engineering.

2. Current Method

As described in the introduction, there is no recognized standard approach to define the extent of area which cryogenic spill protection insulation applied. Therefore, engineers define the extent of brittle fracture hazard area, and cryogenic spill protection insulation area by deterministic approach (e.g., 3-5m from potential cryogenic spill equipment), or refer risk analysis results by exceedance curves which can be produced only when detailed engineering information available.

2.1 Deterministic Approach

Deterministic approach is simple method to define the extent of cryogenic spill hazard. However, because of the lack of the technical justification, the extent will be concluded in conservative side, or contrary under engineering design against the realistic hazard scenario.

2.2 Risk Analysis

To complete the risk analysis, detailed engineering information (P&ID, plant/piping layout) is necessary, and there is no recognized method for the risk analysis (criteria of extent of hazard, method to define the leak source, direction of the extent, etc.). Even if the extent and thickness of cryogenic spill protection insulation should be decided in early phase of the engineering to proceed the other detail design, the risk analysis result is finalized only when required detailed engineering information available.

3. Simplified Method

3.1 Overview

To resolve the constrains of the current methods in above, simplified and appropriate method is established. Following steps is the overview of the simplified method.

- For the less congested area (e.g. on the pipe line/pipe rack), point source approach is applied. Define the credible leak hole size per flange.
- For the congested area (e.g. equipment module, process area), generic source approach is applied. Define the credible leak hole size based on the analysis of leak in LNG liquefaction facility
- Based on the defined credible leak hole, define the extent of brittle fracture hazard area

3.2 Point Source Approach

In the less congested area in the LNG liquefaction facility (e.g. pipe rack/line), the leak source of the process fluid is limited. Therefore, point source approach is applied to define the credible leak hole size, i.e. each flange is considered as leak source of the cryogenic fluid. Based on the OGP (The International Association of

Oil&Gas Producers), the leak hole size for 1E-4/yr leak frequency is 3 to 10mm. Therefore, 5mm is proposed as credible leak hole size for each flange.

3.3 Generic Source Approach

In the congested area in the LNG liquefaction facility (e.g. process module), many leak sources of the process fluid are located in the limited area. Therefore, generic source approach is applied to define the credible leak hole size, i.e. leak frequency from each flange is summed up per the associated equipment. The extent of brittle fracture hazard area is considered from the equipment in this approach. Refer to section 3.4 LNG leak scenario analysis in LNG liquefaction facility in detail.

3.4 LNG leak scenario analysis in LNG liquefaction facility

The LNG leak scenario analysis is conducted based on the existing onshore LNG liquefaction facility information. Figure 1 shows the simplified process flow diagram of LNG liquefaction facility which have potential to cause LNG liquid leak. In accordance with the previous research by the Authors (Hiroya et al., 2016), vapour phase leak is not considered as critical hazard to cause the brittle fracture hazard. Therefore, only the cryogenic liquid phase from the facility is considered in the study. Based on the process condition, the cryogenic liquid handling section is divided as indicated in the vertical lines in figure 1. Table 1 shows the example of process and LNG release conditions (pressure, temperature, liquid fraction, etc.) for each divided section.

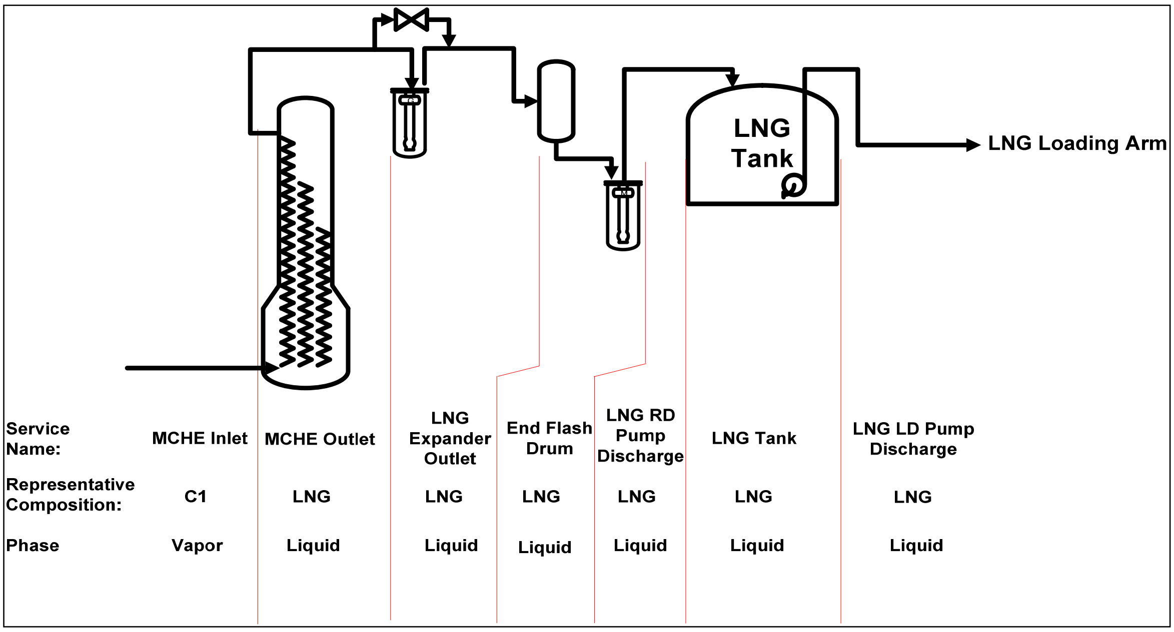

Figure 1: Simplified Process Flow Diagram

Table 1: Process and LNG Release Conditions

Service Description	LNG Expander Outlet	End Flash Drum	LNG Rundown Pump Discharge	LNG Loading Pump Discharge (Tank Top)
Process Pressure [kPaA]	568	105	610	855
Process Temperature [℃]	-143.5	-160.2	-158.3	-159.7

For each section, release frequencies are calculated based on the parts count of "For Construction" (i.e. engineering completed) P&IDs and UK OGP Release Frequency Data. Figure 2 shows the example of exceedance curve of the section for LNG rundown pump discharge section and LNG loading pump discharge section.

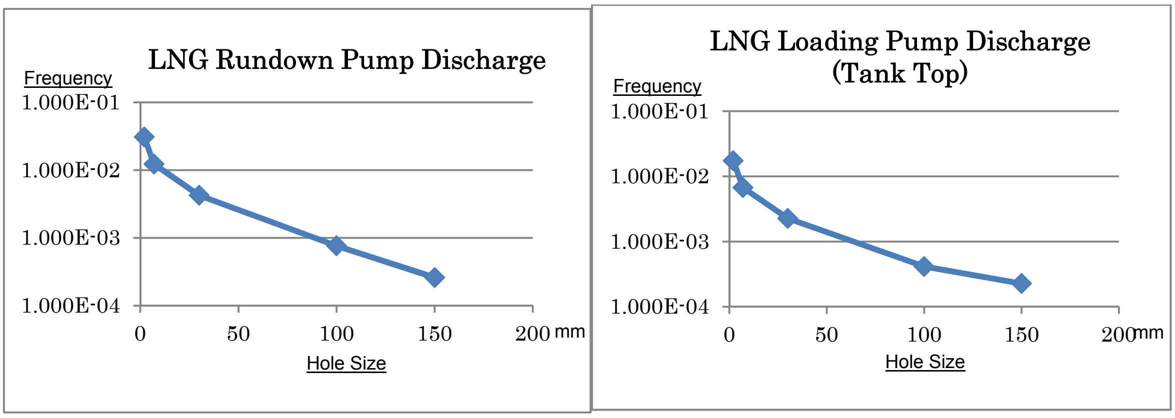

Figure 2: Example of Exceedance Curves for Release Hole Size

To define the appropriate credible leak hole size considering the actual possible hazard, two factors are introduced. Such kind of consideration of the factors is the common approach for the design of steel structure against fire event and/or blast event. For the credible leak hole size to define the extent of brittle fracture hazard area, direction factor 0.25 is applied because the cryogenic release from leak point is directional. In addition, brittle fracture of the steel structure is only occurred if additional load is applied on the steel structure during the exposure by cryogenic liquid leak. To reflect this phenomenon, cold brittle failure probability, 0.1 is also applied. Figure 3 shows the updated exceedance curves for release hole size after considered the direction factor 0.25 and cold brittle failure probability 0.1.

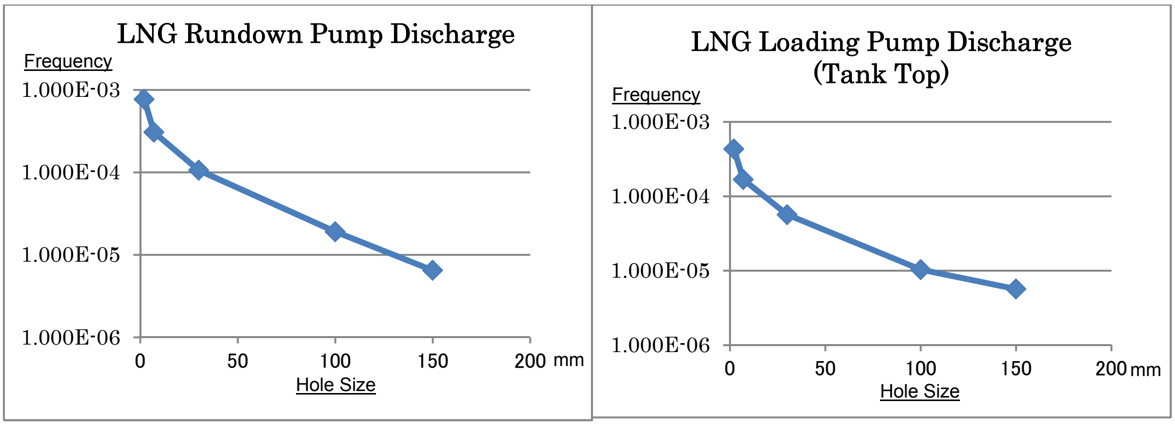

Figure 3: Example of Exceedance Curves for Release Hole Size considering Factors

To define the credible leak hole, the most common frequency risk criteria, 1E-4/yr is applied. Then, it is concluded that 10mm can be proposed as credible leak hole size for each section. For the section where leak point is limited and single source approach is applied, 5mm is used as credible leak hole size as described in section 3.2.

3.5 The extent of Brittle Fracture Hazard Area

Based on the defined credible leak hose size in above, the extent of brittle fracture hazard area is defined by the simulation. In the simplified method, the credible leak hole size to define the extent of brittle fracture hazard area is pre-defined per divided process section described in section 3.4 because, as a common practice, the number of flanges on the cryogenic liquid line are minimized as much as possible in the LNG liquefaction facility to minimize the probability of cryogenic leak hazard. Based on the pre-defined credible leak hole size, the extent of brittle fracture hazard area is simulated per the divided section with the input of actual process condition. The cryogenic spill hazard area is considered as the extent of the LNG liquid droplet travel distance because the cryogenic liquid contact on the structure will cause the brittle fracture hazard (wet condition on the surface on the structure cause the significant temperature drop). The heat transfer from cryogenic liquid to the steel structure is explained by the heat transfer from cryogenic liquid to the surface of steel structure and from the surface of steel structure to the steel structure. Once the heat transfer reaches at the surface of steel structure, the steel start cooled, and cryogenic spill protection insulation will be required to avoid brittle fracture.

The important criteria to affect the heat transfer from cryogenic liquid to the steel structure is whether cryogenic liquid will reach as liquid or fully vaporised gas on the steel structure. In general, boiling heat transfer coefficient is much larger than gas heat transfer coefficient. Therefore, it is assumed that if cryogenic liquid reaches the steel structure, the temperature drop of the steel structure is significant and if cryogenic liquid is vaporised before reaching the steel structure, the temperature drops of the steel structure become much lower, and this distance is considered as the extent of brittle fracture hazard area from cryogenic hydrocarbon spill. Simulation and Experimental Test are conducted to determine the extent of hazard area against the leak hole size. Several tests have been conducted by liquefied nitrogen (LIN) to ensure the adequacy of simulation (Hiroya et al, 2016). Based on the simulation, extent of brittle fracture hazard area can be defined per the leak hole size in accordance with each section process condition.

Table 2 shows the example of the simulation result of extent of brittle fracture hazard area based on the credible leak hole size defined in this approach and process condition. For the section “LNG Rundown Pump Discharge”, the generic source approach is applied because the area is congested. 10mm leak hole size is applied as credible leak hole size as defined in section 2.6. Based on the simulation for this process condition and leak hole size, the cryogenic liquid droplet will reach 7.1m. Therefore, 7.1m from LNG rundown pump is defined for the brittle fracture hazard area. For the section “LNG Loading Pump Discharge (Tank Top), the point source approach is applied because the area is less congested. 5mm leak hole size is applied as credible leak hole size as defined in section 2.6. As per the simulation, the cryogenic liquid droplet will reach 5.9m. Therefore, 5.9m from each flange is defined as the brittle fracture hazard area in the section of LNG Loading Pump Discharge (Tank Top).

Table 2: Example of Extent of Brittle Fracture Hazard Area

Service Description	LNG Rundown Pump Discharge	LNG Loading Pump Discharge (Tank Top)
Process Pressure [kPaA]	610	855
Process Temperature [℃]	-158.3	-159.7
Release Height [m]	1	39
Release Direction	Horizontal	Horizontal
Liquid Fraction	0.98	0.99
Approach (Point Source or generic)	Generic	Point Source
Credible Leak Hole Size [mm]	10	5
Extent of Brittle Fracture Hazard Area [m]	7.1	5.9

4. Comparison with Other Methods

The proposed simplified method is assessed against the current other methods explained in section 2, e.g. deterministic approach and risk analysis. Proposed simplified method require only basic engineering information such as process fluid diagram and overall facility layout which are commonly available at the early phase of the engineering period. The study duration to define the hazard area is shorter than the risk analysis which require detailed design information and long study period. And deterministic approach has less technical justification, but the simplified method has an adequate technical background supported by experimental test to define the extent of brittle fracture hazard area. As a conclusion, by the proposed method, the extent of brittle fracture hazard can be finalized in early engineering phase, and technically well justified. Table 3 shows the summary of current methods and proposed simplified method.

Table 3: Summary of Comparison for Methods

	Current Method-1 (Deterministic Approach)	Current Method-2 (Risk Analysis)	Proposed Simplified Method
Safety (Extent of Brittle fracture hazard area)	Unknown (depends on the defined extent)	Adequate	Adequate
Technical Justification	Less technical justification	Adequate	Adequate
Input	Basic engineering information only	Detailed engineering information	Basic engineering information only
Schedule (study duration)	Short	Long	Short
Schedule (timing to define the extent)	Early phase	Late phase	Early phase

5. Conclusions

The simplified method to define the cryogenic spill hazard area in LNG liquefaction facility is proposed. The proposed methods are verified by the experimental trial test.

Credible Leak Hole Size and Location

Two approaches (point source approach and general source approach) is applied depends on the congestion level of the area in the facility. Credible leak hole size to define the extend of brittle fracture hazard area is proposed based on the example of the actual LNG liquefaction plant design information. 10mm credible leak hole size for congested area (generic source approach), and 5mm credible leak hole size for less congested area (point source approach) is applied.

Extent of Brittle Fracture Hazard Area

Based on the defined credible leak hose size, simulation method is proposed to define the extent of brittle fracture hazard area, supported by the experimental test using liquified nitrogen. The simulation can be conducted by Phast liquid fraction calculation. Based on the comparison with the experimental trial test, the simulation result is considered as reasonably conservative to apply during the design phase.

The proposed simplified method is analysed against the current available methods (deterministic approach and risk analysis, and considered as appropriate, from safety and schedule point of view.

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