Preliminary Risk Analysis of a Liquefied Natural Gas Regasification System in an Offshore Unit

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ABSTRACT

Nowadays, LNG Import Terminals (where the storage and regasification process is conducted) are mostly onshore; the construction of these terminals is costly and many adaptations are necessary to abide by environmental and safety laws. Moreover, an accident in one of these plants might produce considerable impact in neighboring areas and population; this risk may be even worse due to the possibility of terrorist attack.

Under this perspective, a discussion is conducted about a vessel known as FSRU (Floating Storage and Regasification Unit), which is a storage and regasification offshore unit, that can work miles away from de coast and, because of this, can be viewed as an option for LNG storage and regasification.

The goal is to develop a Preliminary Risk Analysis, which will map potential hazardous events, equipment and operation of critical points at the FSRUs Regasification System, based on the Reliability Theory and the Risk Analysis Theory. This analysis is essential to define a maintenance plan based on the Reliability Centered Maintenance.

The results intend to clarify the operational risks of the system and might improve the development of an effective maintenance plan, which can provide good operability with appropriate safety levels.

INTRODUCTION

Natural gas is becoming an important energy source option, as it is clean energy as compared with traditional fuels and a significant alternative to diversify the national matrix energy. However, in general, the production centers is much far of the consumers; therefore, in order to guaranty the economical viability of this source, the development of liquefied natural gas (LNG) transport, which reduces the original volume amount in 600 times, and the regasification technologies are essential.

In this view, a new option to supply LNG arises, the Floating Storage and Regasification Unit (FSRU). As the regasification process usually occurs on onshore plants, the processing in vessels (offshore) is pioneering. These vessels were used just for transporting liquefied gas, but it were transformed to be enabled to gasify LNG. Due to the offshore regasification process being a recent process, with no failures history for analysis and maintenance plan development, our goal is to perform a preliminary risk analysis and build a base for developing an efficient methodology for building an appropriate maintenance plan for the regasification system.

Preventive maintenance is crucial in this case, because an accident with liquefied natural gas may be catastrophic, causing personal, environmental and materials damages.

THE REGASIFICATION SYSTEM

As mentioned previously, the system studied is the regasification system of a FSRU. Since the 1940s, vessels have been used for LNG transportation; however, these vessels began to process the gas regasification and directly supply the net pipes just a few years ago. The regasification process adds new hazards to operations, because besides LNG, there is now compressed gas in process. Accidents along this process may reach the storage tankers causing huge fires or explosions.

In the vessel studied, a Cascade System was used, shown in Figure 1. In this system, the LNG is heated in two stages. At first, by propane compact heat exchanger, its temperature increases from 13.15º K to 263.15ºK. In the next stage, the gas is heated by sea water in a shell&tube heat exchanger, and the temperature reaches 288º K. The propane used in the first phase works in a closed loop. Outside the LNG heat exchanger, its temperature is about 268,15ºK and it is liquefied; hence, it is pumped into a titanium heat exchanger and heat, by sea water, until 273ºK and vaporizes. It then returns to the LNG exchanger.

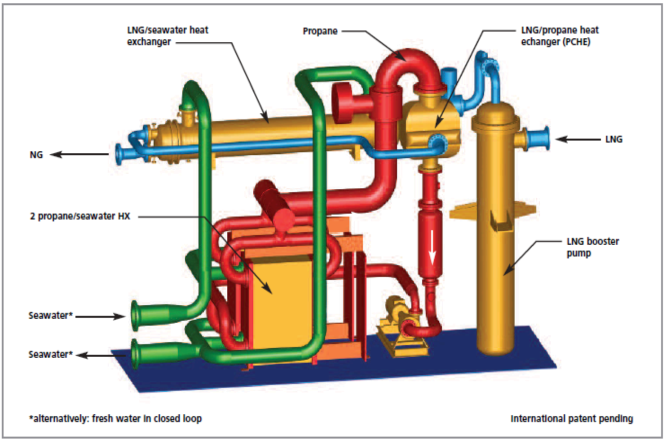

Figure 1. Regasification System (Source: Hamworthy site)

In this cycle, there are hazardous elements: LNG, compressed natural gas and propane.

NATURAL GAS

Natural gas is a hydrocarbon mix composed mostly of methane (about 98%), followed by propane, ethane, butane, hexane and others substances in minor proportions.

Physico-chemical analyses of natural gas alow drawing some conclusions:

- Natural gas density is lower than air, so it spreads easily and does not pose asphyxia risk in ventilated areas. Yet it may cause asphyxia by lack of oxygen is confined spaces;

- Natural gas poses fire risk if exposed to flame; however, its flammability range is narrow, thus hazards decrease;

- It has a high ignition point; in other words, it does not flare up even at high teperatures;

- Being natural gas composed mostly of methane, natural gas toxicity can be said to be equal to methane toxicity, that is, it will be dangerous just for people exposed to large amounts.

LNG

LNG is natural gas condensed to -160ºC. It is a cryogenic liquid, which presents hazards due to the very low temperature and the high freezing power.

PROPANE

Propane is used in this system due to its thermodynamic properties and low freezing point. Analyzing propane properties, it is possible to draw some conclusions:

- The very low freezing point is appropriate for heat exchange with LNG, since other substances could freeze and cut off the system flow;

- Propane has a high self-ignition point and a narrow inflammability range, which decreases the risk of explosion.

METHODOLOGIES

PRELIMINARY HAZARD ANALYSIS (PHA)

As ABS (2000) defines the PHA technique is a broad, initial study that focuses on identifying apparent hazards, assessing the severity of potential mishaps that could occur involving the hazards, and identifying means (safeguard) for reducing the risks associated with the hazards.

After knowing the system and elements, it is necessary to identify hazards (IMO 2007) ; for this, the Preliminary Hazard Analysis (PHA) technique was chosen. This analysis allows a better system view, making it easier to understand its operation. Next, hazards are classified and the probable causes are studied.

PHA identified the main hazards and they were classified by severity and frequency, according to tables 1 and 2 parameters.

Table 1. Frequency Classes

Class	Frequency	Description
A	Very remote	Scenarios that happen only if multiple failures occur. It is not expected through the system life cycle
B	Remote	Scenarios related to large equipment failure.
C	Unlikely	Scenarios related to any equipment failure or human fault.
D	Likely	Expected at least once through the system life cycle.
E	Frequent	Likely to occur at least once a year.

Table 2. Severity Classes

Class	Severity	Description
I	Negligible	Events related to no damages or not measureable damages.
II	Marginal	Events related to negligible damages.
III	Critical	Events which cause external environment impact with small recovery time. May cause moderate personnel injury.
IV	Catastrophic	Events which cause huge external environment impact with long recovery time. May cause severe injury or death.

Using these standards, a PHA was developed and the obtained results are shown in Table 3:

Table 3. Preliminary Hazardous Analysis Table.

System or function	Hazardous element	Triggering event 1	Hazardous condition	Potential accident	Effect	F	S	Corrective Measures
1 LNG Tubing	LNG	LNG Large Leak	Enough LNG to cause asphyxia for lack of oxygen	People without oxygen	Personnel injury	A	IV	- periodic inspections in tubing, heat exchangers and pumps; - installation of gas detector and alarms; - workers training;
			Enough LNG to initiate a reaction.	Explosion or fire	Personnel injury and materials damages	B	IV	
		LNG Small Leak	Enough LNG to cause freezing	Freezing when touching skin	Personnel injury	C	III	
			Enough LNG to cause freezing	Tubing and surrounding equipment freezing	Material damages	D	III	
2 Propane Tubing	Propane	Propane Small Leak	Enough Propane to cause freezing	Tubing and surrounding equipment freezing	Material damages	D	III	inspections in tubing, heat exchangers and pumps; - installation of gas detector and alarms; - workers training;
				Freezing when touching skin	Personnel injury	C	III	
		Propane Large Leak	Enough Propane to cause asphyxia for lack of oxygen	People without oxygen	Personnel injury	A	IV	
			Enough Propane to initiate a reaction.	Explosion or fire	Personnel injury and materials damages	B	IV	
3 Natural gas tubing	Compressed natural gas	Compressed gas Large Leak	Enough gas to cause asphyxia for lack of oxygen	People without oxygen	Personnel injury	A	IV	inspections in tubing, heat exchangers and pumps; - installation of gas detector training;
			Enough gas present to initiate a reaction.	Explosion or fire	Personnel injury and material damages	B	IV	

Using the frequencies and severity classes, the risk matrix (Figure 2) is developed (ABS 2003). It shows the risks classes.

Frequency

Severity	A	B	C	D	E
IV	2	3	4	5	5
III	1	2	3	4	5
II	1	1	2	3	4
I	1	1	1	2	3

	Risk
1	Very low
2	Low
3	Moderate
4	High
5	Very high

Figure 2. Risk Matrix

Setting the hazards from the HPA table in this matrix, the number of hazards for each risk class is obtained (Figure 3):

Frequency

Severity	A	B	C	D	E
IV	3	3			
III			2	2	
II					
I					

Figure 3. Risk Matrix of Regasification System

FAULT TREE ANALYSIS (FTA)

As ABS (2000) defines Fault Tree Analysis (FTA) is a deductive analysis that graphically models (using Boolean logic) how logical relationships among equipment failures, human errors and external events can combine to cause specific mishaps of interest. These FTs allow verifying what causes the event and using the diagram, knowing the failures rates, it is possible to calculate the top event probability; the top event is the undesired event that was chosen for qualitative and quantitative analysis.

To continue risk analysis, risks classified as "High" and "Moderate with severity IV", in Figure 3, were chosen to be the top events of Fault Trees (FTs). Figure 4 shows the fault tree of the LNG Explosion event, in which the necessary base elements to trigger the undesired event are exposed. FTs were built for each risk classified as "High" or "Moderate with severity IV", however just the FT of the LNG Explosion will be presented here due to restricted space.

DISCUSSION AND CONCLUSIONS

Adopting the techniques presented in this research, it is possible to check the most significant hazards and their causes. The study illustrated that the PHA technique is effective to conduct the risk assessment for the chosen system. In turn, the Fault Trees are very useful to understand the interactivity between subsystems and equipment.

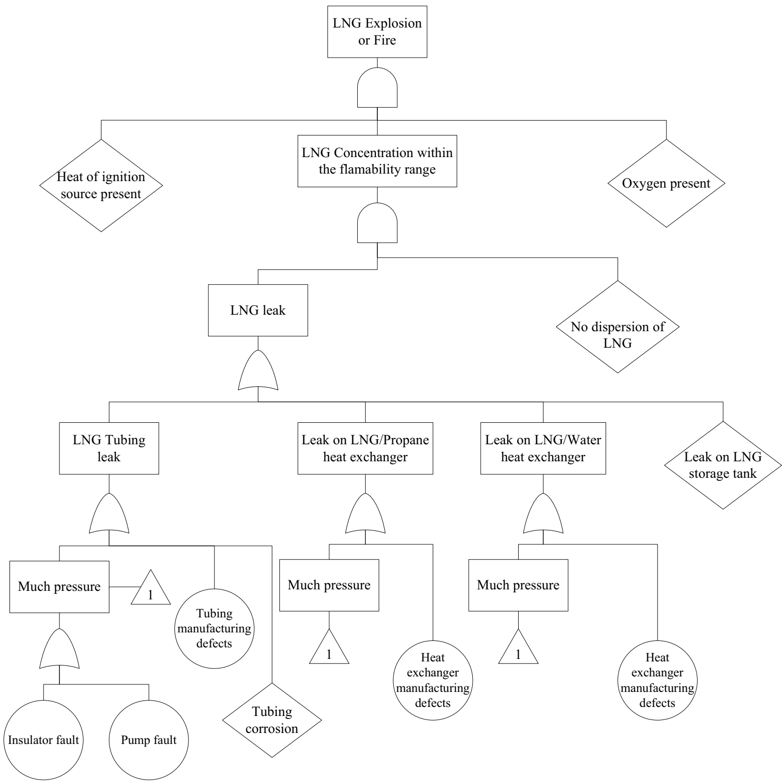

Figure 4. Fault Tree "LNG Big Leak with Explosion or Fire"

To make the analysis more efficient it is essential to get more information about the system and equipment. The detection and alarm systems were not included in this analysis, but they influence the risk analysis, for example these equipments may contribute in LNG or CG dispersion, what will change FTs likehoods. In future works, including these systems in the analysis is recommended. This preliminary risk analysis allowed knowing the main hazards of a FSRUs Regasification System (explosions, fires and freezing) and the more likely causes.

Large leaks deserve attention since they are associated with high levels of severity, mitigating and preventive measures should thus be proposed. Propane and LNG small leaks are classified as High risk, hence deserving attention, too. In both cases the FT analysis shows that the reliability of heat exchangers, pumps and tubes must be high for the use condition; they are the FT base elements.

In the case of pipes, it is worth noting that two elements contribute for occurrence of leaks: increase of pressure and tubing defects.

The increase pressure may be caused by an unexpected heat loss of the LNG or Propane. If the insulator fails and LNG or Propane heat inside tubing, the gas expands and possibly causes a tubing rupture. As a preventive measure it is proposed a control system to supervise heat exchange along the pipe and a meticulous maintenance plan of the refrigeration system.

Tubing defects may be caused by manufacturing defects or pipe corrosion and the LNG constitution is a significant corrosion cause. Thus, this study suggests a tight control of the LNG constitution before the storage tanks being loaded.

The other developed FTs provided more data about the system, however they present many similar base elements, which demonstrates that the mesures proposed above may avoid more than one risk. The FTs also show that the labor training is crucial since it prevents accidents where the worker touches the cryogenic liquid and also prepares the worker to deal with the control and alarm systems.

Other measures suggested are: the implementation of physical protection to avoid pipe rupture on critical locations; periodic inspections; installation of gas detectors and alarms; and labor training. These measures intend to reduce likehood of the potencial events classified as High and Moderate.

This study is a preliminary analysis; it was possible to check the main potential hazardous events and what causes these events. More information about the system is necessary to improve the results. Continuing the risk analysis through the quantitative analysis is recommended, including beyond the history failure equipment expert opinion to improve the analysis.

In this investigation was not found a study about the system operation and the consequences of a regasification system failure in the vessel; a failure in this system may reach other areas of the vessel, such as the LNG tanks, and cause dangerous fires and explosions. Therefore, a future work may study the effects of an undesired event in the regasification system on other FSRU systems.

REFERENCES

American Bureau os Shipping (ABS). (2000). “Risk Assesment Applications for the Marine And Offshore Oil and Gás Industries”, Guidance Notes.

American Bureau os Shipping (ABS). (2003). “Risk Evaluations for the Classification of Marine-Related Facilities”, Guidance Notes.

Ayyub, B.A. (2001) “RISK Analysis for Engineers and Economics”, Chapman & Hall / CRC, EUA.

International Maritime Oraganization (IMO). (2007) − “Liquefied Natural Gas (LNG) Carriers Details of the Formal Safety Assessment”, Maritimar Safety Committee-83rd session-Agenda item 21.

Foss, M. M. (2003). “LNG Safety and Security”. Bureau of Economic Geology.University of Texas. http://www.beg.utexas.edu/energyecon/lng> (Mar. 3, 2010).

Blackwell, B. (2009). “Golar LNG: Delivering the World’s First FSRU”. http://www.golarlng.com>(Mar. 29, 2010).

Hamworthy Gás Systems. (2010), “LNG Systems for Marine Application”. http://www.hamworthy.com/en>(Mar. 3, 2010).