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Evaluation of Plated versus Grated Process Deck in Floating Production Storage and Offloading (FPSO) from Explosion Perspective using SAFETI OFFSHORE

Umamaheswari Porselvam, Hamdan Mohamed Yusoff and Nik Nor Liyana Nik Ibrahim*

Safety Engineering Interest Group, Department of Chemical & Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

ABSTRACT

Vapor cloud explosion is one of the major threats to Floating, Production, Storage and Offloading (FPSO) facilities due to its congested and confined nature. Reduction in explosion overpressure can be achieved by improving the ventilation in FPSO. During early design stage of FPSO, designers consider providing grated process decks to improve the ventilation. However, there is limited research on the comparison of the explosion overpressure between the grated deck and the traditional plated deck. In this study, Vapor Cloud Explosion perspective of plated versus grated process deck in typical FPSO was evaluated by utilizing Det Norske Veritas's (DNV) SAFETI OFFSHORE modelling tool. Representative leak scenarios were selected based on frequency analysis of major accident hazards associated with typical FPSO facility. This study revealed that the overpressure exceedance frequency in plated process deck was higher than the grated process deck for the selected scenario. This serves as quantitative guidance for designers to select an inherently safer type of decks in FPSOs from explosion perspective during the preliminary design stage. However, a detailed Computational Fluid Dynamics (CFD) study is recommended to get an insight of dangers associated with the presence of plated and grated process decks in FPSO, by considering all the parameters and conditions applicable.

Keywords: Grated deck, hazard identification, plated deck, Vapor Cloud Explosion

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E-mail addresses:
uma_sk2003@yahoo.co.in (Umamaheswari Porselvam)
my_hamdan@upm.edu.my (Hamdan Mohamed Yusoff)
niknorliyana@upm.edu.my (Nik Nor Liyana Nik Ibrahim)
*Corresponding author

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INTRODUCTION

Nowadays, Floating Production Storage and Offloading (FPSO) systems are the preferred choice of offshore operators due to its suitability for marginal fields, mild & harsh marine environments. The topside process modules in FPSO are mostly open and aids ventilation of potentially flammable gas from accidental release. However, congestion and confinement in FPSO topsides make it prone to significant Vapor Cloud Explosion (VCE) loads. When flammable materials released to the atmosphere, dispersed and found ignition source after some time delay, will result in VCE. The main factors determining the consequences of VCE are the type of fuel, ignition source, cloud size, turbulence, confinement, and weather.

Type of Fuel

To form a vapour cloud, the released material must be inflammable and at suitable concentrations in atmosphere between Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) (Nolan, 2018).

Ignition Source

To initiate the explosion, an ignition source is required. More severe explosions may result from higher energy ignition sources compared to lower energy ignition sources.

Cloud Size

VCE results only when the adequate size of flammable vapour cloud is formed before ignition, otherwise the ignition results in a large fire, jet flame or fireball. VCE was analysed and found delay times from 6s to as long as 60 min. The study on historical data on ignition delays, reveals that ignition delays from 1 to 5 min is enough for generating the most probable vapour cloud explosion (Lenoir & Davenport, 1992).

Turbulence

For the VCE to occur, the flame front should accelerate at specific speeds, this depending on turbulence inside the vapour cloud. Interactions of flame front with obstacles such as process equipment, pipe rack and structures result in turbulence. The explosion overpressure and the flame speed are directly proportional to each other. The flame speed influences the blast overpressure strongly. In the absence of turbulence, under laminar or near-laminar conditions, flame speeds are too low to produce significant blast overpressure.

Confinement

A rapid increase in explosion overpressure results when the cloud is confined by obstacles, during combustion. The degree of confinement in FPSOs, with their congested equipment topside modules layout and structures, is usually high which makes it more prone to VCE.

Weather

Stable atmospheres lead to large vapour clouds. The Pasquill stability classes, neutral-D, slightly stable-E and stable-F leads to very large vapour clouds.

VCE is not the prominent hazard which influences the concept selection decision, but this is the foremost concern from fire accidental events perspective. After Piper Alpha Disaster on July 6th, 1988, the offshore industry is more focus on preventing, reducing and eliminating the probability of the fire and explosion. But still, accidents occur. There are about 14 explosions and 257 fire incidents were reported at floating units in the United Kingdom continental shelf between 1990 to 2007 (Oil & Gas UK, 2009). In many cases, the release of hydrocarbons and fire may be a more important mode of escalation than direct structural damage (Brighton et al., 1995). Hence it is important to put a substantial amount of work towards reducing the risks associated with fire and explosion in offshore facilities.

The assessment of explosion risk analysis in offshore safety cases by Brighton et al. (1995) suggests optimizing the natural ventilation to avoid vapour cloud explosion in offshore structure. Large scale experimental stoichiometric natural gas/air explosions by Tomlin et al. (2015) prove that high and destructive overpressures can be formed even from explosions in enclosures with no congestion when the vent opening prevents adequate discharge.

By enhancing natural ventilation in FPSOs, the likelihood and consequence of VCE can be reduced by diluting and dispersing the vapour cloud. This can be achieved by providing grated decks instead of plated decks in process deck level 1. The Piper Alpha case study by Holdo et al. (1998) explored the dangers connected with grated floors in offshore structure based on qualitative and quantitative approach; Qualitative approach situates, large vapour cloud formation due to diffusion of flammable vapour to other parts of platform, caused the accident, and quantitative CFD study results in lower explosion overpressure in presence of grated deck. The study of the effect of 30% grated deck in cargo deck explosion of FPSO by Berg et al. (2000) utilized computational fluid dynamic modelling revealing that an average of 25% reduction in explosion overpressure at cargo deck was achieved while using grated process deck. However, there is a very limited amount of study on explosion simulation introducing a grated deck in FPSO, making it difficult for the present designer to take qualitative decisions on using plated or grated decks, as explosion risk reduction measure. The lack of information and guidance on the risk associated with grated process deck in FPSO makes it significant for the explosion prospective evaluation of plated versus grated process deck.

The objective of the study was to evaluate the influence of the presence of plated and grated process deck in a typical FPSO facility by quantifying the potential overpressure exceedance frequencies. Therefore, the following steps were detailed and reported within this study:

i. Identification of major accident hazards associated with typical FPSO topside process modules
ii. High potential leak scenario identification by frequency analysis
iii. Explosion simulation of typical FPSO in with plated and grated process deck
iv. Evaluation of results

The study utilized DNV's Safety Offshore modelling tool for explosion modelling. The typical FPSO facility studied is an external turret-mounted type offshore floating installation, intended to operate approximately 175 km offshore and 2300 m water depth in the Dutch part of North Sea. The FPSO facility is 200 m in length and 50 m in width and capable of producing 120 to 150 barrels of oil per day. The FPSO is in the preliminary design phase.

MATERIALS AND METHODS

The overall methodology framework of this study is given in Figure 1.

Figure 1. Overall methodology framework

Hazard Identification

Initiating release events that could result from Major Accident Hazards (MAHs) in typical FPSO facility were identified through Hazard Identification (HAZID). The methodology applied for HAZID used in this study was based on identifying top events resulting from hazards associated with hydrocarbons in the topside of typical FPSO and its causes, consequences, preventive controls and mitigation measures (ISO 17776, 2000).

Frequency Analysis

The likelihood of potential occurrence of the identified MAH associated with topside hydrocarbon processes was estimated by frequency analysis using historical leak frequency data and "parts count" approach. The failure case selected for this study was process leaks from topside modules. Leak size was selected based on hole size. The representative hole size used in this study was 25 mm to estimate the likelihood of potential release scenario. The topside hydrocarbon process modules which were identified as major accident hazards in HAZID were further divided into isolatable sections, by sectionalizing based on the locations of isolation valves that are intended to operate in the event of a detected release. Parts Count for each isolatable section was done by counting of each piping, valves and fittings along the hydrocarbon process lines. The valves, flanges and pipes were counted based on their diameter, D and divided into 3 categories which are (i) small, D ≤ 3”, (ii) medium, 3” < D ≤ 11”, and (iii) large, D > 11”. The failure frequency for each isolatable section was calculated using Equation [1] by multiplying the sum of the number of components (parts count) by historical failure rate corresponding to 25 mm hole size (Spouge, 1999).

$$F = \sum_{i=1}^{n} n_i f_i \quad [1]$$

Where:
n_i = number of components i
f_i = failure frequency of components i

The high potential leak scenario was selected by comparing the calculated failure frequencies for individual isolatable section.

Explosion Analysis

The high potential leak scenario for topside process modules was processed through SAFETI OFFSHORE V7.53 software to find the effects of VCE in typical FPSO facility with plated and grated process deck. The following failure cases modelled for process release event are (1) no isolation and blowdown functioning, (2) system with only blowdown functioning, (3) system with only isolation functioning, (4) system with isolation and blowdown functioning

The wind speed and atmospheric conditions widely influence the behaviour of vapour cloud explosions and their consequences. For this study, a wind speed of 7 m/s, the average potential wind speed measured in the Dutch part of the North Sea offshore was considered (Brand, 2008). The FPSO is swiveled around the turret mooring and always located at the downstream of the prevailing wind. Pasquill stability class D, which is a typical atmospheric stability class for offshore conditions regardless of wind speed (Oil & Gas UK, 2009) was selected for this study.

The geometrical model was built in the SAFETI OFFSHORE tool using the typical FPSO layout, deck layout and module equipment layout. Two models were built for this study, one with Plated Process deck and another with Grated process deck. The ventilation inside modules depends on the obstacles like the wall or deck in the direction of the wind. Even though the topside modules are open in all directions, the ventilation is obstructed by obstacles like equipment, pipe racks, walls and decks. In the case of decks, the ventilation differs widely for plated and grated type decks. For plated type decks the ventilation from the direction of the plated deck is considered as zero since the plated deck is solid plate without any opening for ventilation. For the grated deck, the ventilation depends upon the fraction of opening presents in the grated plate. In this study, 50% opening fraction was considered for the grated deck. Physical effects raised from vapour cloud explosion considered were blast overpressure loads, these are analysed in terms of impacts on equipment and structures. The overpressure impact criteria considered for this study is given in Table 1.

Table 1
Overpressure impact criteria

Overpressure	Impact
≥ 0.1 bar	Bridges and lifeboats impaired / cladding blown off / glass projectiles from windows or falling ceilings
≥ 0.35 bar	Heavy damage to buildings and process plant within module, sufficient to cause impairment to escape routes, temporary refuge, and lifeboats

The probabilistic analysis was performed using a Monte Carlo approach to derive the overpressure exceedance curve at each defined target on the facility. The cumulative overpressure-frequency curve from the explosion source defined in the facility provided the overpressure exceedance curve.

Evaluation

The overpressure curves were utilized for the evaluation of the effects of vapour cloud explosion due to the presence of grated and plated process deck in typical FPSO facility.

RESULTS AND DISCUSSION

Hazard Identification

In typical FPSO facility, well fluids and hydrocarbons (liquid/gas) were identified as the major accident hazards with potential severity of a level of '5' in one of the consequence categories of People, Asset, Environment and Reputation.

Frequency Analysis

The probability of potential occurrence of the identified MAHs associated with topside hydrocarbon processes was estimated using historical leak frequency data and "parts count" approach. By comparing the calculated failure frequencies for individual isolatable section, the leak from isolatable section after downstream of Free Water KO Drum (Liquid) to Crude-Crude Exchangers, interstage heaters and inlet of the flash vessel was selected as the high potential leak scenario with the frequency of 1.27E-02 for the typical FPSO facility.

Explosion Analysis

The selected high potential leak scenario was processed through the SAFETI OFFSHORE modelling tool to find the effects of VCE in a typical FPSO facility with plated and grated process deck. For the selected isolatable section, the flammable inventory and process stream conditions are given in Table 2.

Table 2

Flammable inventory process condition for selected isolatable section

Properties	Conditions
Vapor Fraction	0.09
Fluid Characteristic	Slightly Stabilised Crude, Liquid Phase
Density (Kg/m^3)	263.05
Volume (m^3)	34.8
Operating Pressure (barg)	2.5
Operating Temperature (deg. C)	39.6
Molecular weight	238.18

The main deck on the typical FPSO facility was set as an explosion target for this study to obtain the overpressure exceedance curves from the SAFETI OFFSHORE tool. The overpressure exceedance frequency curves were generated by plotting the exceedance frequency versus explosion overpressure resulted from the explosion. From the modelled scenarios of the selected isolatable section, the frequencies corresponding to explosion impact criteria, 0.1 barg and 0.35 barg were compared based on 25 mm hole size and the adopted failure scenarios for this study.

Overpressure Exceedance Frequency

The overpressure exceedance frequency curves of grated and plated process deck resulted from a 25 rmm leak are given in Figure 2 and Figure 3 respectively.

Table 3 summarizes the overpressure exceedance curves for 25 mm leak from Figure 2 and Figure 3.

When no isolation and blowdown functioning in selected isolatable Section of typical FPSO facility, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 19.6% higher than the grated process deck level 1 for 0.1 barg overpressure. For 0.35 barg overpressure, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 10.3% higher than the grated process deck level 1.

Table 3
Overpressure exceedance frequency for 25 mm leak

Failure scenarios	Overpressure Exceedance Frequency per year			
	For 0.1 barg		For 0. 35 barg	
	Plated	Grated	Plated	Grated
No isolation and blowdown functioning	2.674E-08	2.236E-08	1.577E-08	1.430E-08
System with only blowdown functioning	2.263E-07	1.708E-07	1.315E-07	1.164E-07
System with only Isolation functioning	1.801E-07	1.315E-07	1.124E-07	9.630E-08
System with Blowdown and Isolation functioning	9.900E-07	8.030E-07	5.946E-07	5.274E-07

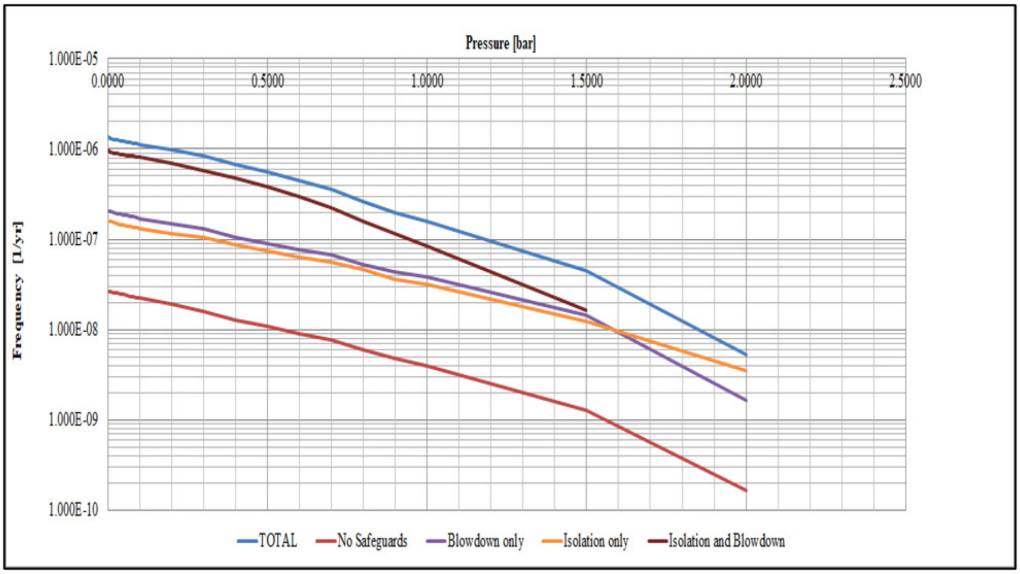

Figure 2. Explosion overpressure exceedance curves for 25mm leak (grated process deck)

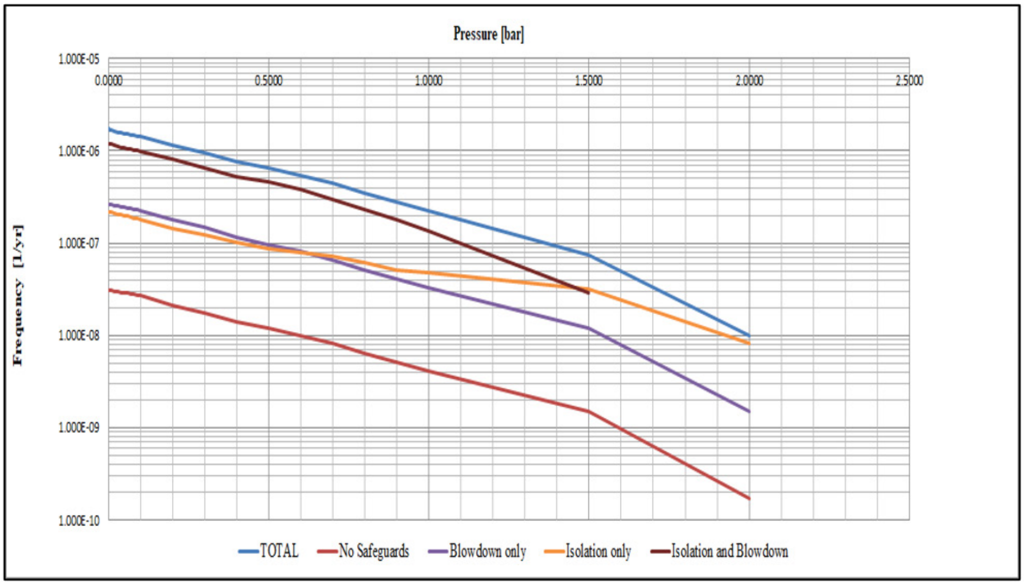

Figure 3. Explosion overpressure exceedance curves for 25mm leak (plated process deck)

Similarly, for the system with only blowdown functioning in selected isolatable Section of typical FPSO facility, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 32.5% higher than the grated process deck level 1 for 0.1 barg overpressure. For 0.35 barg overpressure, the explosion overpressure exceedance frequency in presence of plated process deck level 1 is 13% higher than the grated process deck level 1.

Also, while the system with only isolation functioning, in selected isolatable Section of typical FPSO facility, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 37% higher than the grated process deck level 1 for 0.1 barg overpressure. For 0.35 barg overpressure, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 16.7% higher than the grated process deck level 1.

Likewise, for a system with blowdown and isolation functioning in selected isolatable Section of typical FPSO facility, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 23.3% higher than the grated process deck level 1 for 0.1 barg overpressure. For 0.35 barg overpressure, the explosion overpressure exceedance frequency in presence of plated process deck level 1 was 12.7% higher than the grated process deck level 1.

In selected Isolatable section of typical FPSO facility, all failure scenarios in the presence of plated process deck level 1 led to high explosion overpressure exceedance frequencies compared to grated process deck level 1.

DISCUSSION

The overpressure curves were utilized for the evaluation of effects due to the presence of grated and plated process deck in a typical FPSO facility. In general, industrial practice the total exceedance frequency obtained from the explosion analysis is considered to provide safeguards and alternative design solutions to avoid catastrophic consequences. In this study, for the evaluation of results obtained from SAFETI OFFSHORE simulation, the total overpressure exceedance frequencies for the selected isolatable section with respect to the type of process deck is calculated by adding all exceedance frequencies for all scenarios. For better understanding, the comparison of overpressure exceedance frequencies for plated and grated process decks in typical FPSO are shown in Figure 4.

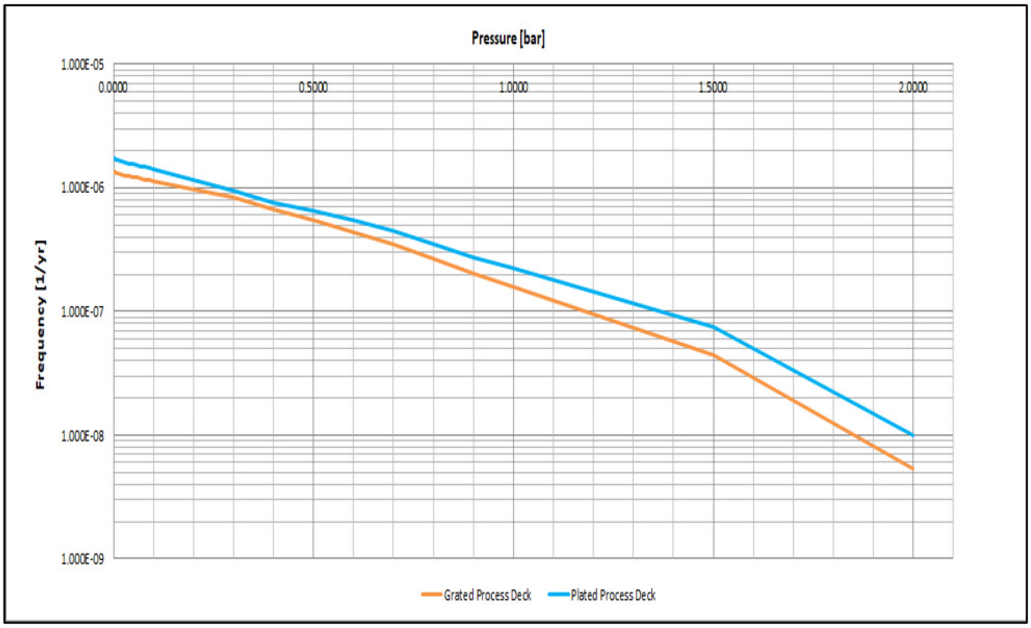

Figure 4. Explosion overpressure exceedance curves for plated and grated process deck

The total overpressure exceedance frequencies for plated and grated process deck in typical FPSO facility are given in Table 4.

Table 4
Total overpressure exceedance frequency

Overpressure	Overpressure Exceedance Frequency per year	
	Plated	Grated
For 0.1 barg	1.423E-06	1.128E-06
For 0. 35 barg	8.543E-07	7.544E-07

From Table 4, it was observed that the explosion overpressure exceedance frequencies for plated process deck were greater by 26.2% than the explosion overpressure exceedance frequencies in grated process deck for 0.1 barg and 13.2% higher in the plated deck than grated for 0.35 barg overpressure. The high explosion overpressure in plated process deck was due to the ignition of the undiluted flammable vapour cloud.

In the presence of grated process deck, the vapour cloud is diluted with natural ventilation and results in less explosion overpressure compared to the plated deck. There is a significant difference observed between the exceedance overpressures frequencies of plated and grated process deck in a typical FPSO facility for the selected isolatable section along with the given process conditions and failure scenarios.

CONCLUSION

This evaluation study focussed on the vapour cloud explosion effects in the presence of plated and grated process deck in typical FPSO facility. The study was supported by Hazard identification, frequency analysis and explosion analysis. In typical FPSO facility, well fluids and hydrocarbons (liquid/gas) were identified as the major accident hazards with potential severity of a level of '5' in any of the consequence categories (People, Asset, Environment and Reputation). Isolatable section from separation module was identified as a high potential leak scenario.

For the selected failure case, process conditions, atmospheric conditions and characteristics of the plated & grated process deck, the overpressure exceedance frequency for plated process deck level 1 was higher than grated process deck level 1. The significant difference between the exceedance overpressures frequencies of plated and grated process deck shows that the grated process deck is advantageous over plated process deck in reducing the effect of vapour cloud explosion at the main deck of typical FPSO facility. Hence the grated process deck can be selected over plated process deck from vapour cloud explosion perspective.

But from the overall safety perspective, the effect of Fire and Explosion on the typical FPSO facility in presence of plated and grated process deck shall be analyzed in detail using computational fluid dynamic study, for all applicable scenarios, process and atmospheric conditions, and weighed against each other carefully before selection.

The selection of high potential leak scenario can be widely extended to other leak sizes and scenarios for explosion analysis to calculate overpressure exceedance frequency across the typical FPSO facility. The leak scenario from the main deck was also considered. This will give a broader picture of the effectiveness of the presence of grated and plated process deck level 1.

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