Hydrocarbon Fire and Explosion's Safety Aspects to Avoid Accident Escalation for Offshore Platform

Muhammad Imran, M.S. Liew, Mohammad Shakir Nasif, Usama Muhammad Niazi and Airil Yasreen

Abstract Offshore platforms are never 100% secure from fire hazard despite of using advanced technology. Hydrocarbon fire and explosion accidents are among commonly reported incidents in the oil and gas process-related activities. In April, 2015, PEMEX-operated oil platform caught fire—45 injured and four died. Accidents such as Piper Alpha have recorded greatest loss of human live on offshore platform in history. A total of 167 persons perished victim of the tragedy confluence of design flows, human error, and bad luck. Saving lives and property in such disaster is extremely a challenging job for engineers. Hydrocarbon fire and explosion produce extreme pressure and temperature, which cause fatalities and structural damages at large scale within a fraction of time. The experimental studies are restricted due to limited facilities available for fire and explosion testing for offshore structure. In previous studies, individual structure member was tested, which cannot represent the behaviour of the entire structure. Therefore, structural safety is always being a main issue to prevent property damage or least-obtained safe evacuation before structural collapse. To understanding the behaviour of structural modelling

M. Imran (✉)
Civil Engineering and Environmental Engineering,
Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia
e-mail: engrimran_ce@hotmail.com

M.S. Liew
Civil Engineering and Environmental Engineering Universiti
Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia
e-mail: shahir_liew@petronas.com.my

M.S. Nasif · U.M. Niazi
Department of Mechanical Engineering, Universiti Teknologi PETRONAS,
Seri Iskandar, Perak, Malaysia
e-mail: mohammad.nasif@petronas.com.my

U.M. Niazi
e-mail: ukniaxi@gmail.com

A. Yasreen
Department of Civil Engineering, Universiti Teknologi PETRONAS,
Seri Iskandar, Perak, Malaysia
e-mail: airil.yasreen@petronas.com.my

M. Awang et al. (eds.), *ICIPEG 2016*,
DOI 10.1007/978-981-10-3650-7_69

techniques allow to study the possible behaviour of the platform. These techniques entirely depend on personal experience and modelling practice adopted in oil and gas sector. Therefore, simulation should be verified by a full-scale experimental study on combined structural members. The standard experimental studies should be conducted and data should be easily available after testing for validation for future simulation and to overcome lack of date issues.

Keywords Disaster · Explosion · Fire · Human · Hydrocarbon · Offshore · Safety · Structure

1 Introduction

Malaysian economy imparts 30% in oil and gas operations. These operations are extremely hazardous due to the presence of highly flammable hydrocarbon fuel [1–4]. Hydrocarbon fuels in funnels are the worst-case scenarios for any offshore facilities which caused massive engineering disasters such as Piper Alpha and Deep Water Horizon. The major hazard among all process-related hazards happened throughout the offshore operation is hydrocarbon fire followed by an explosion or vice versa [5]. The temperature of the fire can exceed more than 1000 °C less than 10 min [6]. Similarly, pressures of explosion released in microseconds, which is extremely challenging to secure structure in time [5]. Lessons learnt from past accidents are not sufficient to predict the safety of structure under such hazardous conditions due to limited experimental data [7, 8]. The Piper Alpha is one of significant disasters in human and oil and gas industry—as happened during Piper Alpha in which 20,000 ton rig vanished just in 1 h 30 min after the chain of events leaving only flare tower and causing 167 precious lives. Indeed, the safety perspectives will be entirely changed because of this accident. Then another devastating incident occurred which shook the entire oil and gas industry that was Deepwater Horizon 2010. It caused a massive oil spill in the Gulf of Mexico, which affected entire marine life almost 5 million barrel oil was spilled in Gulf of Mexico [9, 10]. These types of incidence are not only a loss of property, but also precious lives and company reputation. In case of deepwater horizon only cleaning operation was more than 20 billion USD [11, 12]. Hazard assessment studies such as qualitative or quantitative risk assessment (QRA) [13, 14], fault tree analysis [8], and event tree analysis [15] can predict potential hazard related to process, but it cannot predict the behaviour of structure under extreme fire and explosion condition. Due to limited data from the past event and experiment, it is difficult to predict structural behaviour.

Some platforms are found to be well organised or safety measures are strong that they can evacuate platform safely during accident without any loss of life. For example on 16 February 2007 from Rough 47/3-B platform, during accident all crew were safely evacuated. But unfortunately these examples are extremely rare in oil and gas sector. An example is Ocean Ranger, on 15 February 1982 none of the crew survived when emergency evacuation took place in harsh weather condition. Rescue operation was not performed during such harsh condition. Proper planning and risk assessment safe evacuation strategy while structure in intact could be an ideal condition [16]. Therefore, ensuring safe operation and human safety HSE audit is becoming compulsory for every oil and gas process unit yearly to control these deadly accidents.

These accidents are still not controlled. Recently in April 2015 another offshore platform caught fire in Gulf of Mexico which took 4 workers lives [18, 19]. The purpose of this review was to highlight the need for future studies by reviewing previous studies on the issues causing major fatalities and structural damage due to hydrocarbon fire and explosion, and understand the behaviour of structure under extreme conditions.

2 Offshore Accidents and Damages

Major blast and fire incidents in the offshore industry are caused by human error [20]. The biggest incident which shocked offshore industry was occurred on July 1988 in North Sea. Piper Alpha was extremely productive platform and a largest living facility for more than 200 workers in North Sea. It can produce up to 360,000 barrels oil per day [21, 22]. After first blast and a series of incidents, within 40 min the platform was completely vanished, leaving only the flare tower. The main reason was a minor human error in routine maintenance, which caused a loss of 167 lives out of 228 workers on board. It is known as 'World Deadliest Offshore Industry Disaster'. The accident highlighted various safety issues such as maintenance documentations, poor planning and communication, and failure of safety provisions.

Despite of lesson learnt from past accidents on April 2010 the biggest accident in US history has occurred in Gulf of Mexico on BP's oil rig Deepwater Horizon. The accident occurred on the next day of maintaining its 7 years of safety record. Rig completely sunk within 36 h of continuous burning in Gulf of Mexico. This incident caused 27 billion USD property and 11 precious lives. The blowout resulted massive oil spill in Gulf of Mexico over several months, which entirely disturbed ecosystem of sea [7]. BP has to pay a billion dollars of federal fines to compensate losses. Almost identical sequences Montara well to blow out in Australia just 8 months earlier than Deepwater Horizon [15].

Accidents can be due to sudden blowout of the platform may be due to ship collision, human error, helicopter crash, or natural disaster such as rough weather. It may cause sudden release of hydrocarbon gasses/fuel. These uncontrolled incidents are always threat for billion dollar property, precious human lives, and company reputations for investors [21]. These accidents also cause large-scale environmental damages. Similarly, Montara incident in Australia caused continuous oil spill to 74 days, expected 30,000 barrels oil [23]. Deepwater Horizon on the other hand caused almost 5 million barrels oil spill in Gulf of Mexico [6] which affect marine life. Therefore, it is important to identify expected risks for hydrocarbon blast and explosion to minimise live losses, environmental pollution, and property damages. There are various techniques are used to assess hazard related to fire and explosion. The details will be discussed in the next section.

3 Process-Related Hazards

Hydrocarbon fuel is processed through main separator after being extracted from the reservoir. The crude oil is mixed with oil and gases separated through a sequence of subprocess [7]. The process diagram for oil and gas is described in Fig. 1. It is essential to understand the potential sources of fire and explosion on offshore platform. These sources require special attention to mitigate hazard. A study was conducted by Khan et al. in 2002 to identify process-related hazard [14].

A study was conducted by Khan and Husain in 2002 on risk-based safety assessment to measure the potential hazard related to processing facilities. The hazard was reduced to an acceptable level for offshore facilities using risk-based safety management. The risk for process activities was measured using feedback from detailed qualitative analysis. Different methods and process for predicting potential risk were presented such as event tree analysis (ETA) and fault tree analysis (FTA) [24, 25].

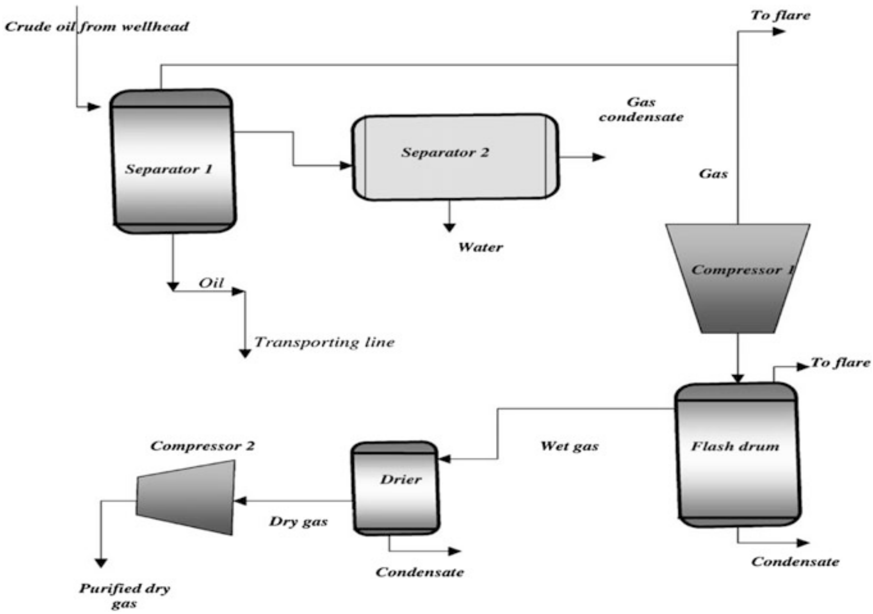

Fig. 1 Hydrocarbon fuel reparation unit and process diagram [14]

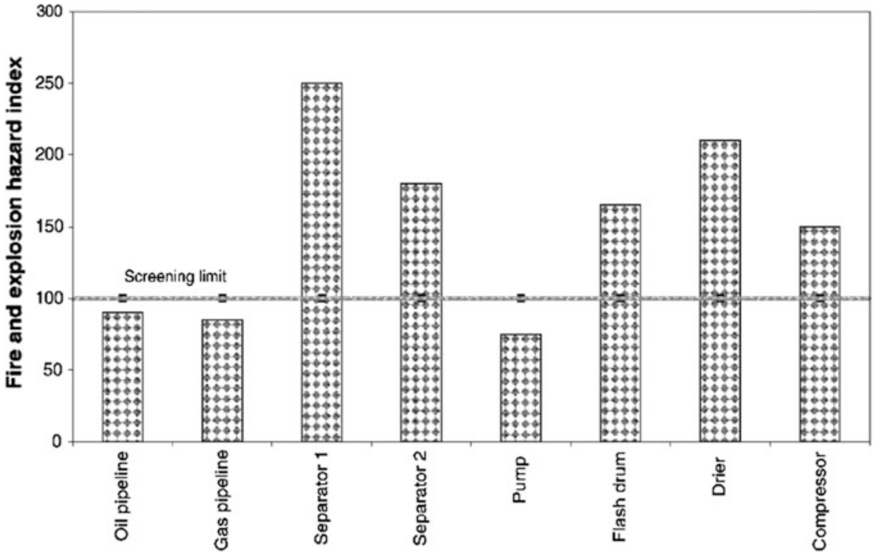

Fig. 2 Hazard Identification Index [14]

The study revealed the severity of each processing unit possessing highest hazard such as separators, compressors, drier, and flash drum. On the other hand, high-pressure oil and gas pipelines were under moderate hazard as shown in Fig. 2. The values of FAR exceed the ALARP acceptance range. These processing units required detailed analysis and safety precaution in order to reduce values to an acceptable range [14]. Compressor 1 has been always in high risk of fire and explosion due to the highest frequency of leakage—critical operation [26]. But it does not mean to avoid other processing units. The risk assessment tools can be used such as quantitative risk assessment (QRA) to assess risk and mitigate as low as reasonable practice without increasing cost of mitigation.

4 Hydrocarbon Fire

The temperature of hydrocarbon can be raised unexpectedly high compared to normal or cellulosic fire [27]. How long structure can sustain during the hydrocarbon fire and explosion for safe evacuation. Steel is most commonly used in offshore structure. Steel lose its mechanical property when exposed to 400 °C. The strength significantly reduces as temperature exceeds 600 °C [28]. The temperature of hydrocarbon fire can exceed more than 1000 °C less than 10 min. This extreme temperature is hazardous to human and causes major damage to structure.

This temperature can immediately cause fatality as temperature increases. The drastic change in temperature causes worst effects on structure as well. The strength of steel structure can significantly reduce between the ranges of 400–600 °C but when the structure is loaded it immediately lose stability. The steel under elevated temperature causes joints to weak under fire. Impact loading would cause serious effects depending upon the type of loading, but the effect is not significant [29]. They involve an extreme explosion and heat flux, which have hazardous consequences for safety, health, and the surrounding environment [24]. The effect on the human body can get third-degree burns when exposed to 72 °C. The temperature of hydrocarbon fire can cause 100% fatalities in a few minutes. Simulation steel uses finite element (FEM) to overcome limitations of the study [30]. Hydrocarbon explosions and fires are extremely hazardous for offshore installations.

5 Hydrocarbon Explosion

The explosion effects are devastating in any oil and gas processing unit. Hydrocarbon fuel explosion can cause extreme pressure instantaneously depending upon the type of leak source. Usually at 10 psi overpressure can cause fatality and structural damage. The human body can survive relatively high blast overpressure without experiencing barotrauma. A 5 psi blast overpressure will rupture eardrums in about 1% of subjects, and a 45 psi overpressure will cause eardrum rupture in about 99% of all subjects. The threshold for lung damage occurs at about 15 psi blast overpressure. A 35–45 psi overpressure may cause 1% fatalities, and 55–65 psi overpressure may cause 99% fatalities [31]. During Piper Alpha, series of explosion and fire caused 20,000 ton steel rig to collapse in an hour and 30 min [21, 22]. Major fatality occurred when living quarters felt down into the North Sea due to instability of structure. Of the total 167 worker killed, 83 workers were in living quarter waiting for rescue operation [6]. Careful considerations should be taken in designing of the structure, equipment layout or arrangement of the facilities to minimise the effects of mishaps or structure instability [32]. Hydrocarbon fuel can cause evolvable massive explosion over pressure and heat flux, which have harmful consequences for structural safety, health, and the surrounding environment [24].

Despite of deep understanding, accidents are still uncontrolled. Individual experimental studies on the structural member cannot represent the behaviour of the entire platform by such studies. The effects could be more severe when member combined loaded member. Testing full-scale offshore platform is not only costly, but also nearly impossible [6]. The only process by which behaviour of entire structure can be observed is through simulation. Only protection arrangement (Active and Passive Fire Protection) is not sufficient to secure structure integrity. The area of risk fire intensity and loading condition played significant role in structural integrity.

6 Conclusion

Following are the conclusions drawn based on the current review:

1. Accidents such as Piper Alpha and Deepwater Horizon are the examples of the worst-case scenario of oil and gas industry. Despite of learning lessons from these accidents, they are not completely prevented. On offshore processing unit Separator 1 possess highest risk of explosion and fire than any other processing unit and required extra attention.
2. During the event of hydrocarbon fire time is extremely crucial to save lives and property damages. As the temperature increased more than 1000 °C less than 10 min within that human body can get third-degree burn at the temperature of 37 °C or when exposed to thermal radiation of 1000 $(kW/m^2)^{4/3}s$. Similarly, 100% fatality observed if body received pressure more than 20 psi. Improved analysis of risk assessment, proper planning, and structure protection hindrance such as blast/fire wall can prevent lives and structural damages, and delay heat radiation/pressure to spread out to other units.
3. The individual experimental study cannot represent the behaviour of the entire offshore platform during fire and explosion. Therefore, it is essential to observe behaviour through simulation and validate results from which experimental study on full-scale frame.

References

1. A. Rajendram, F. Khan, and V. Garaniya, "Modelling of Fire Risks in an Offshore Facility," *Fire Safety Journal,* vol. 71, pp. 79–85, 2015.
2. C. H. Vervalin, "Fire Protection Manual for Hydrocarbon Processing Plants," 1985.
3. A. T. Paterson, *Offshore fire safety*: Pennwell Corp, 1993.
4. J. K. Paik and A. K. Thayamballi, *Ship-Shaped Offshore Installations: Design, Building, and Operation*: Cambridge University Press, 2007.
5. D. Lord, A. Luketa, C. Wocken, S. Schlasner, T. Aulich, R. Allen, *et al.*, "Literature Survey of Crude Oil Properties Relevant to Handling and Fire Safety in Transport," Sandia National Laboratories (SNL-NM), Albuquerque, NM (United States) 2015.
6. M. Imran, M. S. Liew, and M. S. Nasif, "Experimental Studies on Fire for Offshore Structures and its Limitation: A Review," *Chemical Engineering Transactions,* vol. 45, pp. 1951–1956, 2015.
7. N. Khakzad, F. Khan, and P. Amyotte, "Safety analysis in process facilities: Comparison of fault tree and Bayesian network approaches," *Reliability Engineering & System Safety,* vol. 96, pp. 925–932, 2011.
8. F. I. Khan and S. Abbasi, "Major Accidents in Process Industries and an Analysis of Causes and Consequences," *Journal of Loss Prevention in the process Industries,* vol. 12, pp. 361–378, 1999.
9. OGP's, "OGP Risk Assessment Data Directory," International Association of Oil & Gas Producers, England2010.
10. T. Haidar. (2015, The 10 Biggest Oil Spills In World History - 3 Deepwater Horizon Oil Spill. Available: http://www.oilandgasiq.com/integrity-hse-maintenance/articles/the-10-biggest-oil-spills-in-world-history-part-8/.

11. M. Dadashzadeh, F. Khan, K. Hawboldt, and P. Amyotte, “An integrated approach for fire and explosion consequence modelling,” *Fire Safety Journal,* vol. 61, pp. 324–337, 2013.
12. M. Dadashzadeh, R. Abbassi, F. Khan, and K. Hawboldt, “Explosion Modeling and Analysis of BP Deepwater Horizon Accident,” *Safety science,* vol. 57, pp. 150–160, 2013.
13. A. Brandsæter, “Risk Assessment in the Offshore Industry,” *Safety Science,* vol. 40, pp. 231–269, 2002.
14. F. I. Khan, R. Sadiq, and T. Husain, “Risk-Based Process Safety Assessment and Control Measures Design for Offshore Process Facilities,” *Journal of hazardous materials,* vol. 94, pp. 1–36, 2002.
15. C. Jerzy and J. K. Paik, “Paradigm Change in Safety Design Against Hydrocarbon Explosions and Fires,” in *FABIG Newsletter, SCI, Issue 60,,* ed, 2012, pp. 30–38.
16. Y. Pan and L. A. Louca, “Experimental and numerical studies on the response of stiffened plates subjected to gas explosions,” *Journal of Constructional Steel Research,* vol. 52, pp. 171–193, 11// 1999.
17. J. Paik, J. Czujko, J. H. Kim, Sung In Park, MD Shafiqul Islam, and D. H. Lee, “A New Procedure for the Nonlinear Structural Response Analysis of Offshore Installations in Fires,” *Transactions SNAME,* vol. Vol. 121, 2013, 2013.
18. REUTERS, “Accident Aboard Pemex Jack-Up Kills Two, Injures 10” in *Maritime News Today*, ed, 2015.
19. Reuters, “Fire Out at Pemex Processing Platform,” in *gCaptain*, ed, 2015.
20. J. Vinnem, R. Bye, B. Gran, T. Kongsvik, O. Nyheim, E. Okstad*, et al.*, “Risk Modelling of Maintenance Work on Major Process Equipment on Offshore Petroleum Installations,” *Journal of Loss Prevention in the Process Industries,* vol. 25, pp. 274–292, 2012.
21. M. E. Paté-Cornell, “Learning from the Piper Alpha Accident: A Postmortem Analysis of Technical and Organizational Factors,” *Risk Analysis,* vol. 13, pp. 215–232, 1993.
22. D. Drysdale and R. Sylvester-Evans, “The Explosion and Fire on the Piper Alpha Platform, 6 July 1988. A Case Study,” *Philosophical Transactions Mathematical Physical and Engineering Sciences,* vol. 356, pp. 2929–2951, 1998.
23. P. Hart. (2010, 14/Feburay). *Montara Oil Spill: “A Failure of Sensible Oilfield Practice”*. Available: http://www.theoildrum.com/node/7193.
24. J. Paik and J. Czujko, “Explosion and Fire Engineering of FPSOs (EFEF JIP): Definition of Design Fire Loads,” *FABIG Newsletter,* pp. 15–28, 2011.
25. J. K. Paik and J. Czujko, “Assessment of Hydrocarbon Explosion and Fire Risks in Offshore Installations: Recent Advances and Future Trends,” *The IES Journal Part A: Civil & Structural Engineering,* vol. 4, pp. 167–179, 2011.
26. Y. Jin and B. S. Jang, “Study on the Probabilistic Scenario Based Fire Risk Analysis of FPSO Topside Module,” in *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering*, 2014, pp. V04BT02A007-V04BT02A007.
27. Promat. (2014, 05–03–15). *Fire Curves*. Available: http://www.promat-tunnel.com/en/advices/fire-protection/fire%20curves.
28. C. International. PFP Systems [Online]. Available: http://www.pfpsystems.com/assets/Uploads/HydrocarbonBook1.pdf.
29. W. Yu, J. Zhao, H. Luo, J. Shi, and D. Zhang, “Experimental Study on Mechanical Behavior of an Impacted Steel Tubular T-joint in Fire,” *Journal of Constructional Steel Research,* vol. 67, pp. 1376–1385, 2011.
30. M. Jin, J. Zhao, M. Liu, and J. Chang, “Parametric Analysis of Mechanical Behavior of Steel Planar Tubular Truss under Fire,” *Journal of Constructional Steel Research,* vol. 67, pp. 75–83, 2011.
31. R. K. Zipf and K. Cashdollar, “Effects of blast pressure on structures and the human body,” *National Institute for Occupational Safety and Health (NIOSH),* 2006.
32. API, “API RP2A-WSD: Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms–Working Stress Design,” in *Twenty*, ed, 2000.