Fire Safety Journal 61 (2013) 324–337

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

An integrated approach for fire and explosion consequence modelling

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ARTICLE INFO

Article history:
Received 11 February 2013
Received in revised form
29 August 2013
Accepted 3 September 2013
Available online 9 October 2013

Keywords:
Vapour cloud explosion
Pool fire
Jet fire
Accident modelling
CFD
Integrated scenario

ABSTRACT

Fire and explosion are accidents which potentially can occur in oil and gas processing facilities. While fire and explosion could occur as a consequence of each other, most published work has assessed fire and explosion separately, ignoring interactions between the two phenomena.

The current study proposes a novel approach to model the entire sequences involved in a potential accident using liquid and gas release incidents as two test cases. The integrated scenario is modelled using Computational Fluid Dynamics (CFD) codes FLACS and FDS. An integrated approach is adopted to analyse and represent the effects (injuries/death) of the accident. The proposed approach can be used in designing safety measures to minimize the adverse impacts of such accidents. It can also serve as an important tool to develop safety training to improve emergency preparedness plans.

1. Introduction

Several studies have modelled the consequences involved in the release of hydrocarbons. These studies range from advanced CFD modelling to comparison of different tools in accident modelling [1–6].

In a study conducted by Hansen et al. [1], FLACS CFD code was used to simulate the release and dispersion of liquefied natural gas (LNG) and the results were compared with experimental data. As it is a cold dense cloud and is strongly affected by the field characteristics; simulating the dispersion of LNG vapour requires a complex model that considers the influencing factors. Using the FLACS CFD code and comparing the results with experimental data confirmed that FLACS is a suitable model to simulate the dispersion of LNG vapour.

Koo et al. [3] conducted a study to model various accident scenarios at an LNG terminal using PHAST software. Six different scenarios were constructed based on the LNG release hole sizes. Early and late pool fire effects were evaluated through this study. The study concluded that the accident would have an impact on areas outside the plant boundary, and that the late pool fire is a greater hazard than the early one. However, the focus of this study was only on pool fire modelling, ignoring the other more credible scenarios, such as Vapour Cloud Explosion (VCE) and potential interactions. The use of CFD models to better simulate such accidents was recommended by Koo et al. [3].

In a study conducted by Gavelli et al. [4], the consequences resulting from the ignition of a flammable vapour cloud dispersed after the release of LNG during an offloading process were evaluated. FLACS CFD code was used to simulate the LNG spill, pool spreading and vapourization, vapour cloud dispersion and ignition leading to the vapour cloud explosion. The study demonstrated that the FLACS application was able to predict the consequences of accidents; the sequences of events led to a pool fire after the release of LNG and the possibilities of ignition and explosion.

In a study by Kim and Salvesen [5], the explosivity of LNG vapour after the release and formation of a liquid pool was modelled using FLACS. The LNG release occurred in a dike and dispersed to the process area where the source of ignition was located. The explosion overpressure was estimated and mitigation processes to decrease the explosion effects presented. Reducing the thermal conductivity of the subsoil and increasing the height of the dike wall were the mitigation measures proposed to decrease the overpressure as a result of the explosion. While the vapour cloud explosion was addressed, no consideration was given to the pool fire which is a likely scenario occurring after the explosion.

Skarsbo [6] used CFD models FLACS and FDS to model the pool fire phenomenon. Simulation results were compared to experimental data from different sources. The study demonstrated that both models over-estimate the flame temperature. This study focused only on the effects of fire, ignoring the entire sequences involved in such accidents and more importantly interactions of fire and explosion.

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http://dx.doi.org/10.1016/j.firesaf.2013.09.015

LNG release consequences were extensively studied by Mary O'Connor Process Safety Center. The effects of parameters such as high expansion foam, dike wall height and floor conductivity on pool fire behaviour were investigated through these studies [7,8]. The modelling of LNG vapour dispersion and its validation against medium-scale LNG spill tests were also studied [9].

There are also comprehensive studies on the chain of accidents starting from one unit and spreading to different units such as reactors, pipelines, or storage vessels in chemical industries (domino effects) [10–17]. One of the earliest attempts to study the domino effects was the Canvey report, prepared in a proposal of the construction of a new refinery on Canvey Island, UK. Through this study, all interactions between installations in the area were considered to determine risk associated with health and safety [10]. In 1991, the results from the Canvey report were used by Bagster and Pitblado [11] to define a procedure of treatment of the domino effect. Escalation of explosion and its effects on the structures of the plants were also studied in 1996 by Eknes [12]. There was a gap of developing domino effect studies until 1998 when Khan and Abbasi [13] developed a framework of the domino effect analysis (DEA). In this study, a "DEA" procedure was also coded and its application to several case studies was demonstrated. Subsequently, Cozzani and coworkers worked on domino effect analysis using new data [14–16]. In the recent study conducted by Reniers et al. [17], a game-theory approach was developed to investigate the investments of different industries on domino effect prevention.

The above studies consider only individual events such as fire or explosion [4–6]. Combination of the events is more important as one event may lead to another, escalating the overall consequences. In the current study, the authors highlight the importance of integrated accident scenarios and their use in detailed consequence analysis using LNG and methane as hydrocarbons of interest in two test cases. The study is equally applicable to other similar compressed and refrigerated systems involving gases such as liquefied petroleum gas (LPG), natural gas liquids (NGLs) and propane. The major difference between the current study and the domino effect studies is that the current study focuses on an evolving accident scenario which includes one unit and the occurrence of more than one event. The domino effect focuses on the escalation of events from one unit to other units and may include different hazardous chemicals.

1.1. *Hazards caused due to the release of hydrocarbons*

Release of flammable hydrocarbons to the surrounding environment could cause several types of hazard. If a flammable gas leak occurs, a quick ignition may lead to different types of fire such as a fire ball, jet fire or flash fire. The flammable gas could also be dispersed over the area and form a flammable vapour cloud. Then, a delayed ignition could cause Vapour Cloud Explosion (VCE) depending on the level of congestion/confinement. On the other hand, a liquid leak of hydrocarbon could lead to a harmful accident. It may form a pool of liquid followed by vapourization due to the surrounding temperature. An immediate ignition may cause a pool fire. Another possible scenario is the dispersion of volatilized flammable vapour over the area causing the formation of a flammable vapour cloud at a distance from the pool leading to VCE due to a delayed ignition [18].

In a usual accident occurrence, such events do not occur individually. There are interactions among different events causing evolving scenarios. For example, a vapour cloud explosion occurs at a distance from the source of release, the heat load caused by the explosion causes ignition at the release location and a jet fire occurs. Another good example of an evolving scenario is the interaction between the VCE and pool fire due to the release of a liquefied hydrocarbon such as LNG. The release of LNG to land or water could cause a rapidly evaporating pool and subsequent formation of a vapour cloud. An ignition source at any point in the vapour cloud could burn and cause a flash fire. The flash fire does not typically exceed a few tens of seconds; however, if the flash fire burns back to the pool or the ignition starts at the pool, a pool fire occurs. Further, a delayed ignition would provide enough time for the fuel vapour to disperse and form a vapour cloud which if ignited would cause a VCE and resulting overpressure. The heat load after the explosion enhances the vapourization over the liquid pool causing a pool fire [19,20]. Another possible scenario is the Boiling Liquid Expanding Vapour Explosion (BLEVE) which occurs in a case where a vessel, containing a pressurized liquefied gas, is exposed to the heat load caused by a fire or explosion. Increasing pressure inside the vessels causes the rupture of the walls and sudden release of its contents to the atmosphere [18].

In this study, the interaction between the fire and explosion and the resulting consequences are modelled. This type of model can be used to design effective safety measures to prevent and mitigate consequences and to develop efficient safety training and emergency preparedness.

1.2. *Past major accidents and their analysis*

On October 1944, an LNG tank in Cleveland, Ohio failed and released all its contents to the surrounding area including streets and sewers. The LNG then vapourized and formed a vapour cloud. An unknown source of ignition contacted the vapour cloud and a massive fire and consequent explosion in the residential area followed. The explosion led to the deaths of 131 people [21].

In 1988, the Piper Alpha platform, located in the North Sea, experienced an explosion causing 165 deaths and total destruction of the platform. Investigations revealed the release of light hydrocarbons (condensate propane, butane, and pentane) occurred due to the restart of a pump which was out of service for maintenance. Personnel replaced a relief valve (RV) with a blank on the piping flange for the servicing. Restarting of the pump, with no knowledge of the removal of the RV, the flange leaked releasing hydrocarbon gases. The subsequent presence of an ignition source caused the explosion [5]. Investigation reports revealed that the most likely sources of ignition were hot surfaces, broken light fittings, electrostatic sparks, and electric motors. Through the propagation of the fire to module B, the rupture of the B/C firewall caused the breaking of a pipe. Consequently, a large amount of crude oil was leaked in module B causing a fireball in this module. The fire then reached 1200 barrels of fuel stored on the deck above modules B and C while it was spreading back to module C. Thus, the second explosion occurred. The heat load in module B also caused the rupture of the riser followed by an impinging jet fire under the platform [22].

Another LNG accident occurred in the Skikda LNG plant, Algeria in 2004. After a release of LNG, the fuel vapour entered an adjacent boiler through an inlet fan. The fuel mixed with air and the resulting increase in the pressure led to an explosion. The heat load from the explosion reached the fuel vapour near the leak area and caused the second explosion [23].

Other LNG accidents have also been reported by The California Energy Commission [24]. In August 1987, at U.S. Department of Energy Test Site, Nevada, an LNG vapour release occurred and the vapour was ignited by an unknown source. In another LNG accident in Indonesia in 1983, the failure of a heat exchanger due to overpressurization in an LNG plant led to an explosion. In New York in 1973, during the repair of an empty LNG storage tank, a fire accidentally started. The fast pressure increase inside the tank then led to the falling of the concrete dome on the tank and caused the death of 37 people.