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A Methodology for the Hazard Assessment in large Hydrocarbon Fuel Tanks

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This work presents a thorough hazards identification methodology for liquid hydrocarbon fuel storage tanks, by applying a checklist technique on the accident causes and the relevant protection measures, in the framework of implementing the SEVESO Directive series. A forum discussion with Greek industrial safety experts has also been organized by the authors in order to improve and correct any lack of the method. Results are presented and discussed, and it is concluded that the present hazard assessment method helps to identify the major contributors to risk, to improve safety measures and to assist the analysis in these aspects.

1. Introduction

Modern petrochemical complexes, and especially refineries, comprise large storage facilities, which contain, among others, significant amounts of flammable hydrocarbon fuels and chemicals in large storage tanks. Despite the fact that the occurrence of a tank fire accident is a relatively rare phenomenon, its results may lead to unexpected consequences for the installation and also cause potential environmental and health damage that is difficult to assess apriori.
Significant tank fire accidents have happened recently, such as the December 11th, 2005 Buncefield Oil Storage Depots (BOSD) disaster (Buncefield Major Investigation Board, 2008; Herbert, 2010) and the massive tank fire of October 23rd, 2009 at the Caribbean Petroleum Refining. These accidents demonstrate not only the large scale of destruction in the surroundings, together with the implication of potential environmental issues, but also the necessity to prevent these accidents by any means. Studies have been undertaken through literature review with the aim to perform statistical analyses of accident occurrence in storage tanks. The conclusions of such studies are that fire outbursting is the most frequent type of accident in this type of installations, caused primarily by lightning and, in the second place, by maintenance errors.
Intensive research has also been undertaken by many groups of scientists and engineers towards the investigation and explanation of the physical characteristics of the phenomena involved in large hydrocarbon tank fires as by Argyropoulos et al. (2010), Markatos et al. (2009), Vautard et al. (2007), McGrattan et al. (1996) and Ghoniem et al. (1993). These physical characteristics are focused on the estimation of plume dispersion and height elevation, the ground-level concentration of the toxic pollutants, such as smoke, sulphur dioxide (SO_2), carbon monoxide (CO), polyaromatic hydrocarbons

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(PAHs), and volatile compounds (VOCs), together with the characterization of risks zones by comparing the ground-level concentrations with existing safety thresholds.
The present work deals with a thorough hazards identification methodology for liquid hydrocarbon fuel storage tanks, by applying a checklist technique on the accident causes and the relevant protection measures, in the framework of implementing the SEVESO Directive series (European Council, 1982, 1997). A forum discussion with Greek industrial safety experts has also been organized by the authors in order to improve and correct any lack of the method.

2. Accidents in storage tanks

Large liquid storage tanks are used in the petroleum and chemical industries for the storing of both raw material and intermediate or finished products in confined areas that are normally separated from the rest of the installation. The types of tanks for storing combustible or flammable liquid hydrocarbon fuel are classified in three main types by the Institution of Chemical Engineers (IChemE, 2008), as follows:

a) Fixed or cone roof tanks, made of a vertical cylinder side and a fixed cone-shaped roof welded to each other, usually containing “black” heavy products, such as fuel-oils, asphalt (bitumen) and vacuum or atmospheric residue.
b) Open top floating roof tanks, made of a vertical, cylindrical above ground shell similar to the conical roof tank, but with a pontoon type roof, characterized by the ability to rise and fall on the stored-fuel surface, in order to prevent the large volumes emittance of fuel-vapours
c) Internal floating roof storage tanks, a combination of the above consisting of a conical roof with the addition of the internal floating roof or pan that floats directly on the fuel surface, so as to decrease the potential of ignition and to prevent the initiation of tank fires.

The second and third categories of tanks are used for volatile liquid hydrocarbons such as crude oil and “white” light products (jet, diesel and gasoline).
Potential fire scenarios that can be developed in a tank accident are presented in (LASTFIRE, 2001) as follows: rim seal fire; spill on roof fire; full surface fire; bund or dyke fire; pontoon explosion; and Boilover.

3. Hazards identification methodology for liquid hydrocarbon fuel storage tanks

3.1 General steps

A liquid hydrocarbon fuel storage tank farm is a particular type of a chemical installation, in which the hazard stems mainly from the big potential for fire. A hazards analysis should comprise all the general items, such as described by Papazoglou et al. (1992):

- Description of the local area, including a general map.
- Sufficient knowledge of the hydrogeological, hydrographical and meteorological data of the area together with any protected environmental zones.
- Sufficient meteorological data with heavy snow and heavy rain frequencies.
- List of the hazardous installations in the surroundings.
- Ground plan of the plant and/or tank farm together with process flow diagrams.
- Description of production processes for every location of the plant.
- Characteristics of chemical substances according to “SEVESO II”, together with declaration of the stored hazardous substances accompanied by Material Safety Data Sheets (MSDS).

3.2 Proposed methodology for tank inspection

Before going into a full-blown quantitative analysis, this work proposes a screening methodology that can, quite easily, lead to the identification of the areas where a fire can start as a result of a hazardous substance release. The methodology is based on the philosophy of the checklist, namely a catalogue of causes that could lead to the failure of the tank, together with a list of preventive and /or protection measures that can avert the occurrence of an accident in a storage tank. These two lists derive from past experience of tank operation and maintenance, and are to be considered as prerequisite conditions to avoid problems in safety. If an installation satisfies these criteria, then the accident potential is very low without banning risk totally.

3.2.1. Failure causes of tank accidents

The most common initiating events or failure causes for fixed/cone and floating roof tanks are grouped in the general headings presented in Table 1 below.

Table 1: Immediate causes of accidents

1. Operational errors	**4. Static electricity**	**7. Piping rupture/ leak**
Tank overfilling	Rubber seal cutting	Valve leaking
Drain valves left open accidentally	Poor grounding	Flammable liquid leak from a gasket
Vent closed during loading/unloading	Fluid transfer	Piping failure
Oil leaks due to operators errors	Improper sampling procedures	Pump leak
High inlet temperature		Cut accidentally
Drainage ducts to retention basin obstructed		Failure owing to liquid expansion
2. Equipment/instrument failure	**5. Maintenance errors**	**8. Miscellaneous**
Floating roof sunk	Welding/ cutting	Earthquake
Level indicator	Non explosion-proof motor and tools used	Extreme weather
Discharge valve rupture	Circuit shortcut	Vehicle impact on piping
Rusted vent valve does not open	Transformer spark	Open flames/ Smoking flame
	Poor grounding of soldering equipment	Escalation from another unit (domino)
	Poor maintenance of equipment both normal and blast-proof	Accident caused by energy/fuel transportation lines
		Arson (intentional damage)
3. Lightning	**6. Tank crack/ rupture**	**9. Safety supporting systems**
Poor grounding	Poor soldering	Electric power loss
Rim seal leaks	Shell distortion/ buckling	Insufficient tank cooling
Flammable liquid leak from seal rim	Corrosion	Firefighting water loss
Direct hit		Firefighting water in piping freezing

3.2.2. Preventive and protection measures

For all the mentioned causes in Table 1 there are certain protective measures aimed at limiting or preventing their occurrence and they are presented in Table 2.

3.3 Checklist for tank safety assessment

The analysis led the study team to the development of a prototype check list that can detect all of the above causes and protection measures and be a valuable tool in the hands of all safety practitioners, both analysts and installation owners. This list has the form of Tables 1 & 2 having additional space for 'Evaluation' and 'Comments' regarding the awareness of failure causes and the implementation of protection measures by tank farm owners. These remarks are filled out by the person who performs the tank inspection. More specifically, in column "Evaluation" the inspector must complete each cell of the table with the appropriate letter (A, B, C or X), each letter referring to a specific situation observed by the inspector always according to the proposed methodology and findings. The explanation of each letter is as follows: A: Full description (the safety study describes the specific failure cause or protective measure with full details), B: Insufficient description (the safety study does not describe the specific failure cause or protective measure with the appropriate detail), C: Inefficient (the safety study does not include or there is inefficient description of the specific failure cause or protective measure), and X: Inapplicable (the specific failure cause or protective measure is inapplicable to this installation). The “Comments” column contains any comment of the inspector that is important to be referred for the specific failure cause or protective measure.

Table 2: Protective measures

1. Design	**3. Equipment**	**5. Miscellaneous**
Following engineering standards and regulations	Following engineering standards	Safe guarding
Modification of tank top design to prevent overfilling	Handling static electricity during tank loading	Electrical supply of tanks added to critical utilities
Site inspection	Lightning protection system	No smoking/good housekeeping
Safe distance	High-integrity automatic operating overfilling prevention system	Protection against extreme weather phenomena
Dikes, bunds	Arrangements to ensure that the receiving agent has ultimate control of tank filling.	Protection from vehicle bumping
Defining tank capacity	Remotely operated and fire-safe shut-off valves	Protection of piping from mechanical stress
	Protection against fluid expansion in piping	Protection from DOMINO effects
	Temperature monitoring	Protection from areal electric power lines
		Proper labelling and traffic signing
2. Maintenance	**4. Safety supporting systems**	Appropriate management of oily waste
Routine inspection	Fire detection and alarm system	Appropriate management of firefighting water
Periodic proof testing of overfill prevention system/	Firefighting network	Appropriate management of rain water
Corrosion resistance	Foam supply and production system	Good house keeping (5S - Sort, Straighten, Shine, Standardize, Sustain)
Preventive checking of venting equipment	Tank cooling system	
Use proper equipment	Spare firefighting water tank/ diesel driven pump	
Use explosion proof tools	Anti-Frost protection	
Maintenance of both normal and blast proof equipment	Connection of gas detection with the overfilling prevention system.	
Hot work permit	CCTV equipment	
Checking of successful work completion	Emergency Response Plan	

4. Discussion of methodology

In order to verify the soundness of the methodology, the development team has presented it to a group of Greek safety experts coming from big refineries and from commercial tank farm sites and has discussed with them the methodology highlights so as to elicit their opinion considered of high importance. Group discussions have been organised with the operation and safety experts at each site (2 to 3 persons), where the study team presented in a structured manner the items of both Tables 1 and 2 trying to cause the reaction of the experts and register their opinion/suggestions on them. Each group discussion lasted for one and a half to two hours, while the experts had the possibility to send back their remarks in writing. The discussion results together with the elaboration of the experts' written assessment led to the ordering of specified failure causes and proposed measures, on the basis of their significance in the current practice in the visited installations. As most of these companies are directly affiliated to multinational ones (Shell, Esso) or operate under the international state of the art, the study team reckons that the results of this discussion are applicable outside Greece as well. It has been verified that some installation owners are very much aligned, in most safety issues, with the after Buncefield international practice. Additionally, the discussion with the experts has approved in general the findings of the literature and gave rise to some additional remarks-suggestions.

5. Conclusions

In the present paper, an exhaustive hazards identification and good practice methodology for liquid hydrocarbon fuel storage tanks have been presented, aimed at being applied in the Risk Assessment Analysis of any liquid hydrocarbon tank farm; particularly in the ones liable to the European Legislation of the series of "SEVESO" Directives. The methodology gives valuable insight of potential risks to the installations owners and can result in the ordering of tank accident sequences according to their risk severity.

The most common initiating events leading to an accident in a liquid hydrocarbon fuel storage tank together with the preventive and protection measures to be taken have been listed. The innovative part of the present study is the presentation of the check list aimed at helping both safety engineers and safety reviewers to easily identify the major contributors to risk and detail the analysis in those aspects.

Several group discussions has been organised by the authors of the proposed methodology with experienced safety engineers from the Greek petrochemical industries, with the aim to improve and correct any lacks in the methodology. This initiative has helped a lot, as the teams of experts interviewed have significant knowledge and expertise in the operation of liquid hydrocarbon fuel storage tanks and know exactly the critical points behind the safe operation of these installations. Experts believe that this methodology can greatly help in quick the assessment of the safe operation of liquid hydrocarbon fuel storage tanks. The discussion has additionally shown that issues that do not rank high in experts' opinion must all the same be highlighted and adequately ordered within the framework of the SEVESO II type of safety analyses. In particular, the Vapour cloud explosion scenario should be thoroughly analysed, together with the proposal of additional preventive and /or protective measures, so as to minimize its probability to occur, given that the consequences are per definition disastrous.

Moreover, in commercial tank farms, where the safety measures and the expertise are not comparable to the ones of big refineries, additional safety management measures should be taken, such as the in situ observing of tank filling either by an operator or by a CCTV system.

The authors hope that the proposed methodology will be beneficial for safety engineers, safety report evaluators, safety inspectors and process companies, which are involved in the preparation and evaluation of safety studies for liquid hydrocarbon fuel storage tanks.

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