Quantitative Risk Analysis and Consequence Modeling the Explosion of Methane Storage Tanks in a Gas Refinery

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Abstract

Introduction: The major and high quality fossil fuels (oil and gas) have been widely used in various industries such as refineries. It is even though there are very high potentials for hazards in refineries and in the methane gas process, in particular, causing human and financial losses as a result of hazards leading to accidents. This study was aimed to quantitatively analyze the explosion risk of methane gas tanks in a refinery by analyzing the risk, and modeling and evaluating the related consequences. Materials and Methods: Hazard analysis by PHA (Primarily Hazard analysis) was used to choose the worst-case scenario. Then, the causes of the scenario and its probability were determined by FTA (fault tree analysis) Finally, PHAST (Process Hazard Analysis Software Tool) software package was employed to model and analyze the consequences. Results: Based on the results concluded by the preliminary hazard analysis, the explosion of methane gas tank (V-100) was selected as the worst-case scenario at the refinery. The qualitative fault tree showed three factors including mechanical, process, and human failures contribute to gas leakage. The leakage size and weather conditions were effective on the distance of explosion overpressure. Using the consequence modeling, including the discharge, dispersion, and scenario consequence modeling, vapor cloud explosion (VCE) was considered as the major consequence of the accident. Finally, to evaluate the consequence, probit equations were used to quantify losses and the percentage of fatalities due to the methane gas leakage and explosion occurrence. The maximum number of fatalities caused by explosion was 16 persons. Conclusions: In conclusion, the methane gas vessel in the refinery can be considered as the main source of hazard, therefore elimination of the mechanical failures, blast proofing against the explosions, implementation of the safety rules and procedures and personal protection equipment are proposed for decreasing the probable losses and fatalities.

Keywords: Explosion, Gas Refinery, Consequence Modeling, Risk Analysis, Methan, FTA, PHAST, Probit.

INTRODUCTION

The growth of energy supplies is required to meet the human needs and future developments around the world (Dan, Lee, Park, Shin, & Yoon, 2014; Mohammadfam & Zarei, 2015). By the 20th century, more attention was paid to natural gas and oil among the various sources of energy (Dan et al., 2014). A major step for gas production is processing the extracted gas in a refinery, therefore, being operational is a vital need for gas refineries. In such plants, there are chemical hazards, as well as high pressure and temperature conditions in operational units due to the existing reactors and storage tanks. Thus, in spite of all advantages of natural gas, its production, storage, transportation, and usage may result in some hazards such as explosion and fire (E.Zarei, MJ. Jafari, A.Dormohammadi, & V.Sarsangi, 2013). The hazards of natural gas can arise from high flammability and high levels of released energy in the event of explosion or fire(Mohammadfam & Zarei, 2015). Furthermore, the development of urbanization in the refinery area, the growth of these plants, and the increased number of employees can lead to increasing the frequency and severity of accidents and irreparable and hard damages. According to statistics, a lot of events and accidents related to the gas industry have happened in refineries around the world. Hence, the safety of refineries have been thoughtfully considered to avoid accidents and protect the safety of personnel, properties, and the environment (E.Zarei et al., 2013; Tong, Wu, Wang, & Wu, 2016). In recent years, various studies with diverse aims and methods have been conducted on different aspects of industrial safety particularly in process industries related to methane gas. It is obvious that in recent studies less attention has been paid to safety in natural gas refineries than that of other sectors. It is even though there are very high potentials for hazards in refineries and in the methane gas process, in particular, causing

human and financial losses as a result of hazards leading to accidents. In the few conducted studies in refineries, the main focus has been on the risk assessment and analysis, while the modeling and evaluating the consequences of accidents have been less investigated. This study was conducted in a refinery to analyze the risk of hazardous material leakage, model and evaluate the related consequences using the preliminary hazard analysis (PHA), fault tree analysis (FTA), and the Process Hazard Analysis Software Tool (PHAST). To decrease the risk of accidents in the chemical industries, it is necessary to assess the probability and the severity of their consequences. In this regard, this study was aimed to quantitatively analyze the explosion risk of methane gas tanks in a gas refinery.

METHODOLOGY

This study was implemented based on a framework consisting of some steps proportional to the conditions of operational units. The framework included PHA technique to identify the hazard points, FTA technique for qualitative and quantitative analysis, and the PHAST software package for modeling and evaluating the hazard consequences.

Worst case scenarios selection

In this step of the study, the scenarios with the highest severity and probability of occurrence were selected. Finally, after analyzing the results obtained from PHA worksheets, the explosion of methane gas tank (V-100) was selected as the worst-case scenario at the refinery. Operating and Atmospheric conditions related to the study are shown in Table 1 and Table 2.

Table 1. Operating conditions used for discharge modeling

Scenario location	Material composition	Process condition		Volume (m³)
		P (bar)	T (ºC)	
High pressure methane vessel	CH_4	120	45	19

Table 2. Atmospheric conditions corresponding to an operating duration

Atmospheric parameter	value
Wind flow velocity (m/s)	1.2- 5
Atmospheric stability class	D, F
Ambient temperature (°C)	10
Relative humidity (%)	67

Qualitative analysis and determining the repeatability of scenario

As fault Tree Analysis (FTA) can provide much more accurate, specific, and realistic results than the database of accidents, in this study, the FTA method was used. To determine the probability of basic events, the viewpoints of experts, OREDA offshore reliability data handbook, and a study by Khosravirad were used (Khosravirad, Zarei, Mohammadfam, Shoja, & Majidi Daryani, 2016; Participants, 2002).

Consequence Modeling of the Scenario

Consequence modeling aims to determine the increase rate of explosion shock waves in different distances and time intervals relative to the occurrence place of scenario. The

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consequence modeling includes the discharge modeling, dispersion modeling and scenario consequence modeling.

Consequence Modeling

Vapor cloud explosion (VCE) was considered as the major repercussion of the accident. The best-known model to estimate the consequences, TNO Multi-Energy model, was used in this study (Grossel, 2001). The selected worst-case scenario in three leakage sizes of 50, 100, and 250 mm, and in the complete rupture of the tank were modeled using the most appropriate software for modeling Process Hazard Analysis Software Tool (PHAST)7.11. (Al-shanini, Ahmad, & Khan, 2014; E.Zarei et al., 2013; Gant, Narasimhamurthy, Skjold, Jamois, & Proust, 2014; M. J. Jafari, Zarei, & Badri, 2012; Mohammadfam & Zarei, 2015; Parvini & Kordrostami, 2014; Tong et al., 2016; Zarei, Jafari, & Badri, 2013).

Consequence Evaluation

Finally, after consequence modeling, its evaluation was taken into account. At first, damages and losses caused as a result of scenario (VCE) were calculated. In this study, consequence evaluation aimed to determine the percentage of fatalities (Mohammadfam & Zarei, 2015). Valid probit equations were used to quantify the percentage of the population who were exposed to vapor cloud explosion due to methane gas leakage from tank V-100 (M. Jafari, Zarei, & Dormohammadi, 2013; Lees, 2012).

RESULT AND DISCUSSION

After reviewing the existing hazard checklists and hazards analyses (previously conducted), methane gas pressure vessel (V-100) at the pressure of 120 bar and temperature of 45°C was introduced as the main source of hazard and a basis for extracting the selected scenario. Surveying the process and accidents statistics, as well as site inspection, wereled to selecting the explosion of this vessel as an important scenario. The obtained results from analyzing the causes of scenario occurrence using FTA method are as follow: The qualitative fault tree showed that three factors including mechanical, process and human failures contribute to gas leakage from tank V-100. Because of the large size of the drawn fault tree for gas leakage, a part of it has been indicated in Figure 1. After qualitative fault tree analysis, the probability of basic event occurrence was calculated (Table 3) (Khosravirad et al., 2016; Participants, 2002). The results proved that mechanical failures with the failure probability of 0.0899 were the main cause for the occurrence of the selected scenario. The second and third orders were devoted to the process and human failures with failure probabilities of 0.0568 and 0.0439, respectively. The probability of accident occurrence in a year was estimated to be 0.19. In order to model the consequence of the scenario, environmental and operational conditions were studied. Vapor cloud explosion (VCE) was determined as the main hazard related to methane gas leakage from the tank. Figure 2 illustrates the results obtained from modeling the vapor cloud explosion. The maximum area affected by the VCE was related to rupture of 250 mm. In addition, the safe distances from the accident were 633 meters for category 5D and 613 meters for category 1.2F. The results showed that the weather condition and the amount of overpressure had considerable effects on the contours of the worst-case explosion overpressure in all sizes of ruptures (Figures 3 and Figure 4).

Table 3. Failure probabilities and failure rates obtained for three main contributors to scenario occurrence

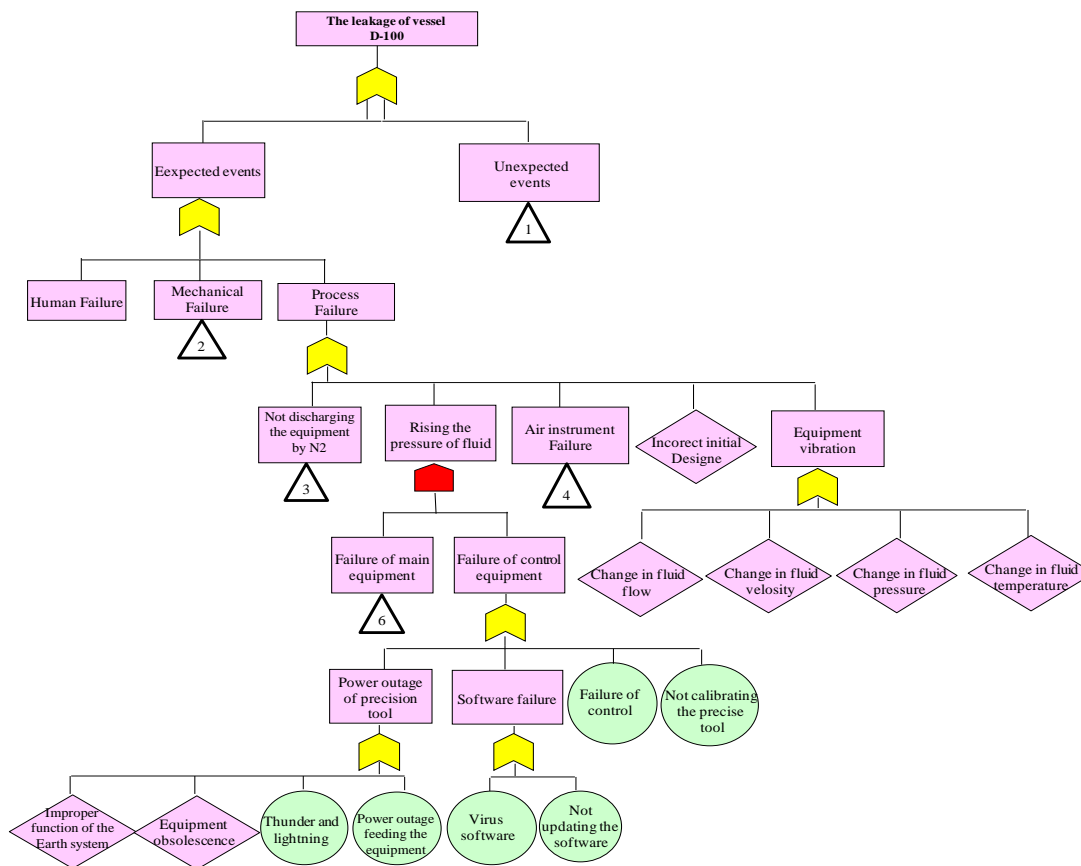| Contributors to gas leakage	No.	Basic event	Failure probability	Total failure probability	Failure rate
Process failure	1	Software failure	0.0014		
	2	Valve failure of precise tools	0.001		
	3	Equipment obsolescence	0.0026	0.0568	0.06
	4	Improper function of the Earth system	0.0018		
	n	--	--		
Mechanical failure	1	Welding failure	0.002		
	2	Destruction of the anti-corrosion layer	0.008		
	3	Abrasion	0.005	0.0899	0.09
	4	Valves obsolescence	0.007		
	n	--	--		
Human failure	1	Stress	0.039		
	2	Shift work	0.04		
	3	Fatigue	0.075	0.0439	0.045
	4	Lack of skills and experience	0.014		
	n	--	--		
Total				0.1906	0.211

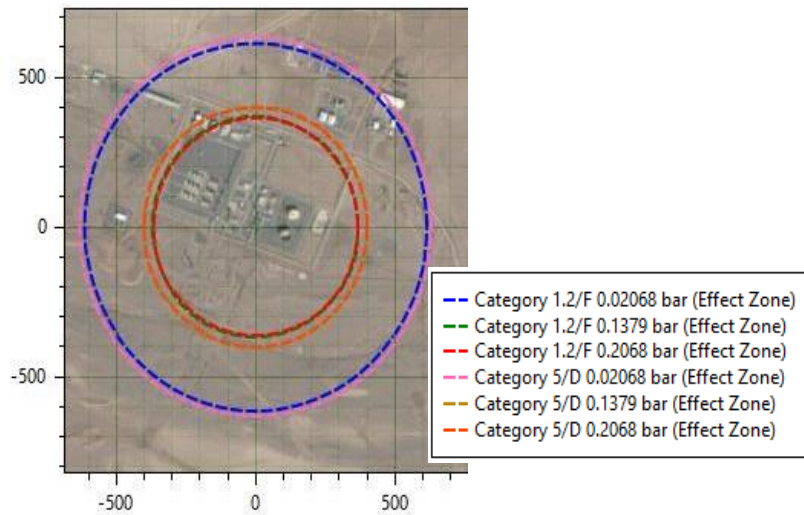**Figure 1.** Fault Tree Analysis drown for V-100

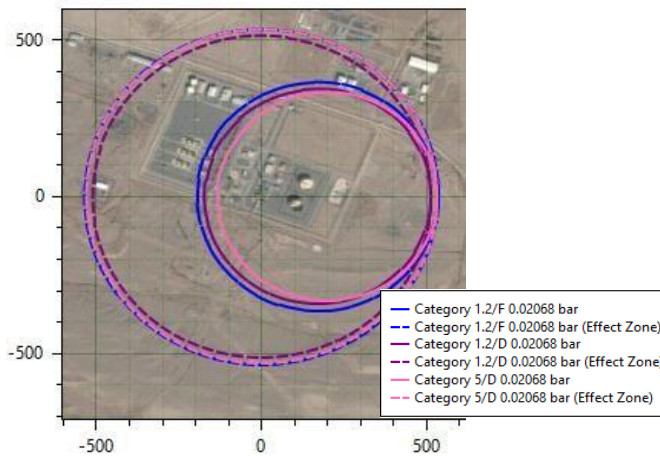**Figure 2.** Late explosion worst case at 250mm leakage

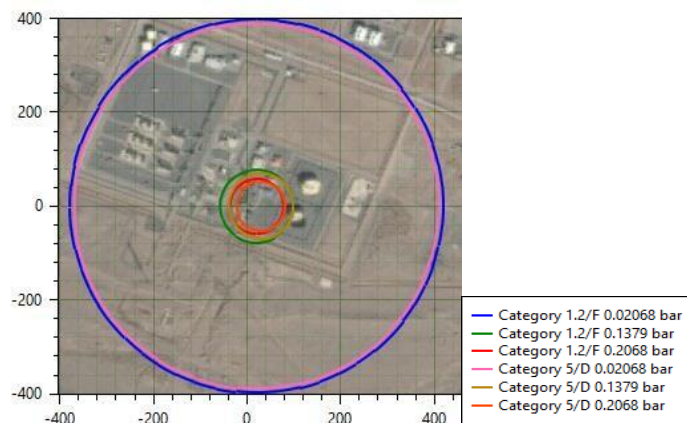**Figure 3.** Late explosion worst case at 100mm leakage

Figure 4. Late explosion worst case at catastrophic rupture

Table 4 shows the affected distances in different criteria of explosion overpressure considering the leakage sizes in three weather conditions. In all leakage sizes, except for catastrophic rupture in overpressure of 0.02 bar, increasing the wind flow velocity had a direct impact on affected distance. However, the atmospheric stability in all scenarios, except for the leakage sizes of 50

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and 100 mm in overpressure of 0.02 bar, had no considerable impact on mentioned distance. In size of 50 mm, the overpressure distance increased with increasing the atmospheric stability (category F).

Table 4. The affected distances (m) in various criteria of the explosion

Overpressure (bar)	0.02			0.1			0.2		
	Weather conditions								
Leakage size (mm)	1.2 F	1.2 D	5 D	1.2 F	1.2 D	5 D	1.2 F	1.2 D	5 D
50	250	232	239	146	133	143	139	128	137
100	535	512	532	262	262	295	257	257	292
250	613	613	633	369	369	401	366	366	401
Catastrophic rupture	419	419	409	97	97	99	78	78	82

The results indicate that the rupture of 250 mm with an overpressure of 0.2 bar will cause the maximum number of fatalities (16 persons). The incurred losses were obtained using the probit equations (Table 5).

Table 5. The number of fatalities in different scenarios based on probit equations

Scenario number	Leakage size (mm)	Effect area (m2)	Probit value	Fatality percent	Fatality number
1	50	58934.66	2.9	5	2
2	100	267728.96	2.9	5	9
3	250	504915.14	2.9	5	16
4	Catastrophic rupture	21113.36	2.9	5	1

CONCLUSIONS

In this study, quantitative risk analysis was conducted for the explosion of methane gas tank in a gas refinery. The fatality rate caused by (VCE) was considered as the main consequence of the accident. The study did not examine the probability of fire occurrence. According to results of the preliminary hazard analysis, methane gas tank (V-100) with an operating pressure of 120 bar and a temperature of 45°C was introduced as the main center of hazard. In this regard, the explosion of tank was surveyed in three sizes of leakage and in the state of catastrophic rupture. Following the analysis of causes of scenario occurrence, the mechanical failures with a failure probability of 0.0899 were estimated to be the most contributing factor for the scenario to happen. Results showed that the leakage size had a significant impact on areas affected by the explosion overpressure so that the maximum and minimum areas were devoted to leakage size of 250 mm and 50 mm, respectively (Table 4). In all leakage sizes, the blast radius can reach to the fire station and control room. Figure 4 illustrates the most dangerous state of vapor cloud explosion caused by the leakage size of 250 mm. By this leakage size, the office building and resorts for refinery workers fall within the scope of the risk. Analyzing the weather conditions showed that in all leakage sizes, except for catastrophic rupture in overpressure of 0.02 bar, increasing the wind flow velocity had a direct impact on blast radius. However, the atmospheric stability in all scenarios, except for the leakage sizes of 50 and 100 mm in overpressure of 0.02 bar, had no remarkable impact on these sizes. In the leakage size of 50 mm, increasing the

atmospheric stability (category F) led to increase of the blast radius (Table 4). Wind speed helps methane dispersion to greater distances, therefore a larger area is affected by the explosion occurrence. The maximum number of fatalities (16 persons) caused by explosion occurrence was obtained for the leakage size of 250 mm in the category of 5D. Considering the policy for expanding the studied refinery and attracting more workforce as well as the development of urbanization in future, accident occurrence can cause more losses and fatalities than that of the present study. In conclusion, the application of appropriate devices for detecting the leakages, elimination of mechanical failures, and using the suitable and practical measures to decrease the probability and severity of potential accidents are proposed for decreasing the probable losses and fatalities.

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