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Evaluation of the Explosion Hazard of a 1-Butene Tank in a Polymer Complex Based on Consequence Analysis

Mostafa Pouyakian [a], Rozita Farhadi [a,*], Mohammad Javad Jafari [a], Fatemeh Zarei [b]

[a] *Department of Occupational Health Engineering, School of Public Health, Shahid Beheshti University of Medical Science, Tehran, Iran.*
[b] *Department of Occupational Health, School of Public Health, Alborz University of Medical Sciences, Karaj, Iran.*

 Corresponding author. E-mail address: r.farhadi88@yahoo.com

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ABSTRACT

Background: Nowadays, the reduction of incidents, their effects and their consequences have become one of the priorities of organizations. Despite all the efforts made in various sectors to reduce events, every year, there are many events that threaten industrial societies. In order to mitigate the effects of these incidents, prediction and planning are critical to dealing with them. Therefore, the purpose of this study was to evaluate the risk of explosion of 1-butane reservoir in a polymer complex based on an analysis of the outcome using the PHAST software.
Methods: This study was conducted in one of the Kermanshah petrochemical complexes in 2016. Necessary geographic information and other basic information were collected. 16 probable scenarios were selected and consequences modeling was done by PHAST software.
Results: The modeling results showed that full rupture scenarios and leakage scenarios from the 150 mm hole are the most dangerous scenarios.
Conclusion: The results of modeling showed that the larger the leakage size, the associated consequences would be more dangerous and consequently more losses. Due to the capabilities of studied company and the readiness level of the company, it has the ability to respond to the first scenario to some extent.

1. Introduction

Life in a safe and risk-free world has always been a desire for human beings, and paying attention to safety is an intrinsic sense in humanity driving him to effort to survive [1]. Despite the many efforts of factories and industries in the management of chemical safety, there is always the possibility of a devastating and fatal incidents [2].

Chemical industries often deal with high-risk chemicals under high temperature and high pressure conditions. Therefore, it is likely to occur events such as explosions, fire and toxic leakage [3].

Meanwhile, chemical reservoirs have contributed greatly to catastrophic events. The tanks are part of the industrial facilities for the storage of petroleum and chemical materials.

These tanks are susceptible to a variety of accidents that may have severe consequences for

humans, the environment and equipment [4]. 1-Butene is an organic chemical compound in gas form and has a chemical structure of C_4H_8, highly flammable, soluble in alcohol, ether and benzene, and explodes in contact with oxygen [5].1-Butene often stored in large spherical reservoirs in liquid form. Due to the low heat of evaporation, it is immediately evaporate after release into the environment.

The evaporated part of liquid is heavy (more than twice as heavy as the surrounding air) and make a vapor cloud which poses a great deal of danger to the health of exposed people.

Full burning of 1-Butene results to production of water and carbon dioxide, and in the absence of sufficient oxygen, incomplete burning occurs and produces carbon monoxide [6]. 1- Butane in the National Fire Protection Association (NFPA) ranked first in health hazards and four in flammability [7]. 1-Butene is stored in spherical reservoirs. Spherical reservoirs are generally used to store light gas and light gasoline, generally light chemicals and to withstand high pressures, and may withstand pressure of up to 100 pounds per square inch or more [8]. In Iran, along with development of petrochemical industries, the potential for industrial accidents has increased.

One of the major incidents that threatens the process of industries is the Vapor cloud explosion. A cloud of vapor usually charges due to leakage of lubricating liquid vapor or gas. This incident will have sever consequences. One of the consequences is creating increased pressure on existing buildings in the area. By modeling and achieving the amount of pressure on the building, the level of damage to the building and the probability of mortality are determined, and with the frequency of the incident, the risk level of the building is determined [9]. In the study of Golbabaei et al. in an industry in the eastern part of Tehran, the Vapor cloud caused by the propane explosion was investigated. The results of consequence modeling showed that the explosion resulted in the loss of about 916 personnel and 130

vehicles, as well as a financial loss of at least 401 billion USD.

Incident modeling simulation to estimate the consequences of explosions on peoples and buildings could be done by the PHAST software.

Currently, the best software package available for modeling and evaluating the consequences of accidents is PHAST Risk 7.11 [10].

This software is one of the most popular software in the field of risk analysis. It has the ability to model a wide range of pure lightweight chemicals, heavier than air, and a mixture of chemicals based on mathematical equations [11].

The validity of this software package has been evaluated by researchers such as Hanna et al. [12].

The software output can be considered as a measure for the compilation of maximum areas affected by hazardous concentrations due to material leakage, and thus it is possible to formulate preventive control measures during and after the event [13]. Tony Ennis et al. modeled the Vapor cloud in 2006 with PHAST software, which suggested that there is often a lack of sufficient understanding of source specifications for VCE gas dispersion conditions. Kasashki et al. also examined the consequences of a possible disaster in the oil refineries of the country. The results indicate that LPG storage tanks are the most dangerous part of the refinery due to the explosion wave [14]. In the modelling study of Behrouzi (2012) consequences of probable incidents and the individual risk of the workstation were estimated.

Ultimately practical solutions were presented to increase the safety level of the station [15].

Reducing accidents and their consequences is one of the priorities of any organization. Despite all the efforts made in various industries to reduce the amount of events, every year, many incidents threaten the industrial societies and cause major damage to the environment, equipment, as well as causing injuries, disabilities, and death. In order to mitigate the effects of these incidents in such circumstances, which are known as emergency situations, it is vital to anticipate and plan events to deal with them.

Therefore, the purpose of this study was to evaluate the risk of explosion of 1-butene reservoir in a petrochemical complex based on the consequence analysis using the PHAST software.

2. Materials and Methods

This study was carried out in one of the complexes of polymeric petrochemical complex in Kermanshah in 2016. The total area of the industry was 60 hectares. A total number of 708 personnel were worked in this industry distributing in three work shifts. 120 workers were in day shift and 588 people were in the evening and night shift.

Population density in the day shift was 0.0002 individual per square meter and at night shift was 0.001 individual per square meter. The reservoir used in the petrochemical plant is a spherical pressurized reservoir containing 1-butene. The storage capacity of the reservoir is as high as 500 cubic meters, the diameter and height of the tank are 16 and 18 meters, and the temperature and pressure of the tank are 25 centigrade and 2.5 bar respectively. The methodology is based on the standard method of Debt Norske Verities and the American Institute of Chemical Engineering, which is used to assess the quantitative risk in chemical, oil, gas, petrochemical and transportation industries [16]. It consists of 4 steps: (1) collecting information such as unit geographic location, flat or mountain, latitude and longitude, of the process units for quantitative risk assessment, (2) identification of possible scenarios based on the importance of its casual factor, (3) modeling and evaluating the various consequences of an incident that can cause losses or physical damage or financial damages, and (4) determining the likelihood of occurrence of a scenario. After collecting the necessary geographic information, the PHAST software manual was used to identify the hazards. According to the software manual, these hazards (leaks and tears in the reservoir) were identified and evaluated based on incidents occurring in the reservoirs over the past years. The size of the gap created on the reservoirs was determined using the size of the pipes connected to the reservoir. After determining the size of the leak, its qualitative grading was performed using the tables provided by DNV Company. Then,

based on the identified risks, probabilistic scenarios were selected. For each of the scenarios, factors affecting the formation and progression of that scenario, such as the output phase, and the material density were determined. Meteorological data from 1972 to 2014 was used to determine the ambient temperature and wind speed. For the dominant winds in the city, it is westward. The selected scenarios were modeled using the PHAST software. Four states of defect (worst-case Scenarios) were considered for a single-phase 1-Butene reservoir and simulations were made for day condition in four. As a result 16 scenarios were determined to be analyzed. Finally, based on the findings from the observations and scenarios carried out by PHAST software, the preparation level of the industry to encountering with emergency situations was evaluated.

3. Results and Discussion

The most important and main consequence of the explosion is the wave of pressure created by the sudden release of the energy contained in the explosive substance (super-vapor). As shown in Fig. 1, the pressure range is 0.22 bar. It is exceeds the petrochemical site.

According to PHAST software manual, probable incidents can cause defects in vessel or reservoir's wall ranging from minor holes to full rupture which leads to leakage of flammable or poisonous substances.

In this study, the selected scenarios in terms of leakage size in the tables presented by DNV Company were studied in four qualitative conditions including small, medium, large and full rupture leakage. The greatest radius affected in the full rupture of the reservoir. The maximum intensity of the flash fire radiation is related to the leakage of a 150 mm hole with a radiation intensity of 40 kW/m^2. The most affected radius is also the leakage of the 150 mm hole in the 12th scenario (winter) with a radius of 155.6 m.

The lowest radiation intensity of the jet fire is from leakage of a 10 mm hole with a radiation intensity of 190.4 kW/m^2. The least affected radius is related to a leakage of 150 mm hole with a radius of 400 m (Table 1).
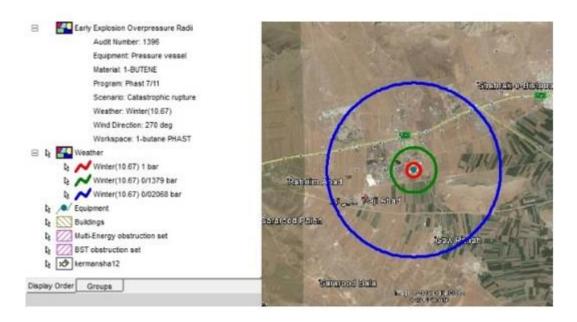
Fig. 1: The affected area by vapor cloud explosion due to full rupture of the reservoir in the winter.

Table 1: The radius of the affected area and the radiation intensity of jet fire.

	Hole size (mm)															
	10				**50**				**150**				**Full rupture**			
Season	S	M	A	W	S	M	A	W	S	M	A	W	S	M	A	W
Scenario code	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Radiation intensity	200.9	191.9	198.81	190.4	318.63	304	315.15	302.2	400	400	400	400	173	173	173	173
Consequences	1 to 99 percent fatality of exposed population, complete destruction of buildings															
	S: Spring, M: Summer, A: Autumn, W: Winter															

The worst scenario of flash fire is the full rupture of the tank in the spring (scenario 13). The radius affected by this scenario is 2530 meters.

The lowest area affected by the leakage from the 10 mm hole in the fall season (scenario 3) with a radius of 10 meters. According to this, the highest mortality rate related to the full rupture of the reservoir is in the 13th scenario with a radius of 2530 m (Table 2).

Table 2: The radius of the affected area and the radiation intensity of flash fire.

	Hole size (mm)															
	10				**50**				**150**				**Full rupture**			
Season	S	M	A	W	S	M	A	W	S	M	A	W	S	M	A	W
Scenario code	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Radiation intensity	26.9	33.15	10	92.14	105	119	106	114	304	347	303	328	2530	1938	2386	1771
	S: Spring, M: Summer, A: Autumn, W: Winter															

The simulation results showed that full rupture scenarios and leakage scenarios of the 150 mm hole are the most dangerous scenarios of the 1-Butene storage tank. Death rates due to flash fire and fire emergencies were determined in different scenarios based on the guidance of the PHAST software.

Based on the results obtained from the software, the probability of mortality of all individuals present at the polymer petrochemical Complex (708 people) is the same as predicted. The most vulnerable scenarios were thirteenth to the sixteenth scenarios. The least vulnerability is related to the first scenario, due to the pressure wave and the area affected by the maximum distance affected by the full rupture of the reservoir in the spring (scenario thirteen). The radius affected by this scenario is 2530 meters.

The least affected area is affected by a 10 mm hole in the spring (first scenario) with an impact distance of 86 mm. The safe distance for a fire and emergency situation was estimated at 60 and 155.6 m, respectively.

4. Conclusion

This study was conducted to evaluate the risk of explosion of 1-butene reservoir in a polymer complex based on the consequence analysis. The results of modeling showed that the larger the leakage size would be, the associated consequences would be more dangerous and, consequently, more losses.

In the scenario of the full rupture of the pressure vessel, the highest risks and losses were observed.

In the event of a full rupture, due to the fact that the volume of the released material is higher than other scenarios, the risks and losses are higher than that. Also, the results of modeling showed that with regard to environmental conditions, atmospheric stability, wind speed and ambient temperature, there is a possibility of more severe risks in the winter than in spring. The results of this study are in agreement with the study of Jafari et al. (1393) and Golbabaei et al. (1394) [17] and there is little differences with Mortazavi's study (2011) [18]. Jet fire modeling showed that the

highest mortality rate was related to 150 mm leakage with a radiation intensity of 400 kW/ m^2.

Considering that the closest units to the 1-Butene tank are 500-unit and water unit that 167 and 441 meters far from 1-Butene unit respectively, the radius of jet fire will not cover that units and as a result mortality rate will be 0 in these units. Another factor that prevents of reaching flames of jet fire to these units is the dominant direction of wind in the area of the industry (Kermanshah city). The dominant wind's direction in the city is from the northwest to the south-east, which is not within the complex direction. The flash fire modeling showed that the highest mortality rates were related to the full rupture of the reservoir and leakage from the hole of 150 mm. The radius affected by this scenario is 2530 meters, which is consistent with the study of Jafari et al. They also found the highest mortality rate due to sudden and immediate fire due to the full rupture scenarios [19]. In this study, the worst scenario is the full rupture of the reservoir in the spring. The safe distance for a flash fire and jet fire was estimated to be 60 and 155.6 meters, respectively, less than that of Jafari et al. (1392), respectively 180 and 250 meters [19]. The probable cause of the greater safety distance associated with fire and sudden fire in the Jafari's study with the present study is greater operating conditions (temperature and pressure, respectively, 450 ° C and 25 ° C in the hydrogen production unit) and greater range between lover flammable limit and upper flammable limit (between 4 to 75%), rather than operating conditions (temperature and pressure, respectively, 70 ° C and 10 ° C) and flammability range (1.6 to 10%) of 1-Butene. On the other hand, according to Mortazavi et al. the risk distances in the summer season are higher than in winter [20]. According to the Duffy study (2007), the safe distance is the mass of the released material and the density in the environment (barriers) [21]. In the present study, by increasing the size of the leak, more volume of the material is released which subsequently has more destructive effects. Regarding the consequences of the explosion of a reservoir containing a 1-Butene that is flammable and as seen in the modeling results, any potential leakage from the reservoir will have catastrophic consequences. By modeling the distribution of materials by valid software like PHAST, in addition to defining the range of affected area by

toxic, flammable and hazardous leakage, the control program (including preventive and reactive responses) can be designs based on the modeling results [22]. Based on the results of modeling, the probability of mortality in the present population of 708 people in the polymer complex of petrochemicals is equal to one. Therefore, due to the capabilities of the Polymer company and the obtained innovations, the polymer company has the ability to respond to the first scenario (least vulnerable) to some extent. It is possible to reduce the consequences significantly by using smaller reservoirs in the construction phase of industry and by modifying the operating conditions (pressure and temperature). The surrounding buildings should be covered with fireproof materials. It should also be used for explosion resistant materials and small and reinforced glass.

Regular and planned maneuvers should be put on the agenda for training of staff [23].

Acknowledgment

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