Original Article

Modelling the Consequences of Explosion, Fire and Gas Leakage in Domestic Cylinders Containing LPG

Mohammad Hosein Beheshti[1], Somayeh Farhang Dehghan[2], Roohalah Hajizadeh[3], Sayed Mohammad Jafari[4] and Alireza Koohpaei[5]*

[1]Department of Occupational Health, Faculty of Health, Gonabad University of Medical Sciences, Gonabad, Iran; [2]Department of Occupational Health, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [3]Occupational health engineering, Work Health Research Center, Qom University of Medical Sciences, Qom, Iran; [4]Occupational health engineering, Faculty of Medicine, Khatam Al-Nabieen University, Kabul, Afghanistan; [5]Department of Occupational Health Engineering, School of Health and Occupational Health Research Center, Qom University of Medical Sciences, Qom, Iran

Corresponding author:
Alireza Koohpaei,
Occupational Health Department, Health Faculty, Work Health Research Center, Qom University of Medical Sciences, Qom, Iran,
Tel: +98-2537835522; Fax: +98-2537833361;
E-mail: koohpaei19@yahoo.com

Abstract

Background: One of the substances with a high potential of damaging that nowadays is used widely in industry and human environment is LPG gas cylinders. **Aim:** The purpose of this study is modeling the consequences of gas leakage in domestic cylinders containing LPG (Liquefied petroleum gas). **Subjects and Methods:** The factors affecting discharging and emissions of LPG gas in 26, 60, 78 and 107 liter cylinders were described. ALOHA software was used as one of the best software for modeling gas emissions from tank storage, and emergency response program was presented at the time of the gas leakage based on modeling results. **Results:** The results showed that in all 4 types of examined cylinder up to distance 11 meters around the tank of LPG gas, concentration of gas is 33000 ppm. This area is located in the AGEL-3 that there is the risk of death and threatens the lives of people. In case of full gas leakage from 60, 78 and 107 liters cylinders, respectively at the distance of 11, 12 and 16 meters from cylinders, concentration of gas was about 21,000 ppm that was equal to low explosive limit (LEL). In full gas leakage, the consequences of combustion and explosion of LPG gas to distance 15 meters of cylinder is the most serious danger that threatens the personnel. **Conclusion:** Developing an emergency response plan is essential and will have an important role in limiting the harmful effects in release of gas and hazardous substances.

Keywords: Modeling; Explosion; Fire; LPG; Gas; ALOHA

Introduction

Fires, explosions and emission of toxic material are the main risks of chemical industry. In addition to these industries, the fire and explosion are the most important and most unfortunate events that threats human life in public buildings and high traffic places. The consequence assessment of risks such as the release of hazardous chemicals in the environment is one of the most urgent steps to increase the level of safety in the design phase or activity of industrial units. Prediction of fluid behavior after release and its emissions into the environment is very important to estimate the consequences and possible injuries as well as awareness of the maximum safe radius of fire, explosion and emission of toxic substances, and it can play a crucial role in dealing with accidents in emergency situations. [1,2]

LPG (Liquefied petroleum gas) cylinders are one of the most common sources of fire and explosion. Nowadays in Iran, cylinders containing liquefied gas are used in various sectors such as the kitchens, industries and also in areas that have no gas pipeline network. In small industries where the industrial consumers cannot provide the installation cost of gas tanks or do not have enough space to install large tanks for gas storage, they use 50 kg portable cylinders and connecting it to the gas pipeline in outside the building. One of the properties of liquid gas which makes it dangerous is that this gas usually storage under pressure and at temperature above the boiling point, so any leakage can lead to change its state to steam and gas. This action causes the liquid gas to release occurring hundreds of meters in ambient air before it reaches to the ignition source. [3] LPG's vapor creates an explosive combination at concentrations between 2% LEL (lower explosive limit) and 10% UEL (upper explosive limit) and it can cause severe burns in skin, because of rapid evaporation resulting into rapid decrease in temperature (especially liquid propane). [4] One of the effective methods of prevention is the study of the consequences of accidents using risk assessment methods and atmospheric diffusion models [5] and preparing an emergency response plan. In fact, emergency plan is the final level of protection in a process unit. The purpose of the emergency plan is to organize and increase the preparedness against emergency situations in order to reduce possible damage. [6] It has a great importance to determine the radius of damage during an accident caused by poisonous and hazardous gases. For this purpose, software modeling

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techniques is used. This process is used to determine the margin of safety and danger and so that in the event of such accident, it can able to take people away from the danger zone and reduce casualty rates. Many models have been presented to determine how to distribute the material. Gaussian models are the most widely used models and mass Gauss model is the foundation of all of models. [7,8]

Using computer software can minimize the time taken to modeling events. Today's, multiple software models such as SLAB, DEGADIS, PHAST and ALOHA has been developed to predict the spread of toxic and dangerous materials that each one has particular characteristics that are consistent with its application. [9] Modeling of material emissions by reliable software can define the affected area from leakage of hazardous materials; moreover emergency response program can be planned using the modeling results.

Atmospheric dispersion of hazardous material releases is another important issue. The amount of concentration released in terms of time and distance is one of the main purposes of making model distribution of material in the environment. ALOHA is the strongest and most popular software for modeling the consequences of the release of substances in the environment. [10,11]

ALOHA means "Areal Locations of Hazardous Atmospheres" and is a special computer program that helps us to have better respond against accidental release of chemical, with modeling and forecasting of leakage process. This software is able to predict all consequences of chemical release such as fire, explosion and toxicity materials in the environment. This software has been presented by the Environmental Protection Agency (EPA) for modeling accidents caused by the release of toxic and explosives substances. The software has a very rich database (data for more than 1000 chemical substance) and has simple working environment to avoid user mistakes. [11] Despite the importance of the risk of exposure to chemicals, must have created a program to respond to emergencies. This program should be create according to the nature of different material and relevant risks, risk level and scope of release in a way that have the most effective in the shortest possible time.

In Iran, there is no a pre-formulated plan for emergency response. One of the substances with a high potential of damaging that nowadays is used widely in industry and human environment is LPG gas cylinders. Personnel who work near the area of the leakage and the general population are at risk.

Lack of enough study on process risks and also the necessity of applying the emergency response planning in this area have been led to be ignored risks related to gas emissions. The aim of this study was to evaluate possible scenarios of liquefied gas leakage in domestic cylinders according to emergency levels defined by the center for chemical process safety (CCPS).
Moreover, it was tried to identify the factors influencing the reduction in the area affected by the release of the material and finally to develop emergency response plan in the area of emissions.

Materials and Methods

Research method applying in present study is based on conventional a method which is proposed by American Institute of Chemical Engineers (AIChE) and Det Norske Veritas (DNV) Institute to model and assess the consequences in chemical process, oil, gas and transportation industries. [12,13] To evaluate the consequences of possible accidents, a four-stage model is proposed in Figure 1.

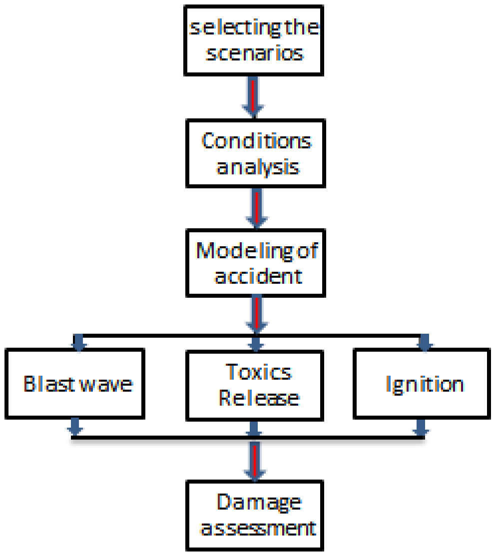

Figure 1: Four-stage pattern to assess the consequences of accident.

Modeling the effects of explosions, fire and gas leakage in 26, 60, 78 and 107 liter domestic cylinders contain LPG has been done. To develop an emergency response plan, the potential risks of the studied site should be reviewed and also the worst possible scenarios have been considered. Characteristics of intended gas cylinders are shown in the Figure 2.

Figure 2: Characteristics of intended gas cylinders.

A sudden leakage of the cylinder, LPG quickly changes the phase and will be released in gas form. It should be noted that the limits of the modeling software is that leakage location must be entered into the software. For this reason, modeling a gas leakage is very hard and has a lot of error except for gas leakage from the drain valve.

The required parameters for the software ALOHA to model a gas leakage from tanks are including site data (source place and time of release), atmospheric data (temperature, humidity, direction and speed of wind, terrain and other atmospheric parameters) and chemical data. In ALOHA software in order to determine the domain of toxic vapor cloud, Acute Exposure Guideline Levels (AEGLs) is used as follows:

AEGL-1

At this concentration, it is predicted that the general population, including susceptible individuals can experience irritation, annoyance and some non-sensory and asymptomatic effects. However, the effects are not disabling and are transient and reversible.

AEGL-2

At this concentration, susceptible individuals may experience adverse and severe effects or irreversible effects. In this case, people may lose their ability to escape.

AEGL-3

At this concentration, people may lose their lives or in other words, expose at this level of concentration maybe life-threatening.

In fact, AEGL is an airborne concentration of toxic vapors that is expressed in terms of parts per million, or milligrams per cubic meter. Moreover, to prepare emergency response program is used ERPG (Emergency Response Program Guideline). ERPGs are values which are used in order to estimate the concentration range.

ERPG-1

Maximum concentration of pollutants in the air which is expected all people who are exposed to this concentration for more than an hour, only experience mild and transient effects or feel the smell of the substance.

ERPG-2

Maximum concentration of pollutants in the air which is expected all who are exposed at levels around or near more than an hour, do not experience irreversible developmental effects or serious adverse effects on health so that not disturbed individual protective and preventive measures.

ERPG-3

Maximum concentration of pollutants in the air which is expected all who are exposed at levels around or near more than an hour; do not experience effects that lead to life-threatening.

This study was conducted under three different scenarios that have been expressed as follows:

Scenario 1: Liquefied gas is leaked from the outlet valve and is distributed in environment:

Part 1-1: Modeling domain of formation of the toxic vapor cloud

Part 1-2: Modeling the flammable domain of vapor cloud of LPG

Part 1-3: Modeling the explosion domain of vapor cloud of LPG

Scenario 2: Liquefied gas is leaked from valve and is burnt in environment as jet fire.

Scenario 3: Cylinder is exploded and liquid gas is burnt as a fireball (Boiling liquid expanding vapor explosion -BLEVE).

In general, the purpose of modeling of gas leakage from fuel tanks under various scenarios using the ALOHA software are as follow:

• Specifying the domain of affected area by toxic and hazardous chemical leakage

• Estimation of material concentrations released in the environment in terms of distance and time.

• Specifying the domain of affected area from the explosion of toxic and hazardous substances

• Specifying the domain of affected area from the combustion of toxic and hazardous substances. [11]

Results

Scenario 1: liquefied gas is leaked from the outlet valve and is distributed in environment

Part 1-1: Modeling domain of formation of the toxic vapor cloud

In this scenario, it is assumed that the gas is coming out of the cylinder outlet valve and creating toxic vapor cloud which is surrounding the tank. The results of graphical modeling of scenario 1 and formation of toxic vapor cloud around the tank is shown in Table 1. In all four studied cylinders, gas concentration was 33,000 ppm around the cylinder to a distance of 11 meters is in the range of AGEL-3 and there is the risk of death and life threatening of people who are in this area. There is no area of AGEL-2 in 26 liters cylinders, but from a distance of 11 meters of 60, 78 and 107 liters cylinders to distances of 12, 16 and 19 meters of cylinders respectively concentration of liquid gas vapor cloud is 17,000 ppm that were in the range of AGEL-2 and in this area susceptible individuals may experience adverse and severe or irreversible effects. According to the results of this study in the full gas leaks of 60, 78 and 107 liters cylinders respectively, at distance of 20, 27, 31 and 35 meters around the tank, LPG concentration is 21000 ppm that is equals lower explosive limit (LEL) of LPG. Moreover, about to 20, 27, 31 and 35 meters around the 26, 60, 78 and 107 liters tank LPG respectively, vapor concentration is 5500 ppm which is located in AGEL-1 range.

Part 1-2: Modeling the flammable domain of vapor cloud of LPG

Results of modeling the flammable domain of vapor cloud of

LPG according to the concentration of flammable gas vapors is shown in the Table 2.

Table 1: Formation domain of toxic vapor cloud at different distances of studied cylinders.			
Variables	**AGEL-3 domain (m)**	**AGEL-2 domain (m)**	**AGEL-1 domain (m)**
107.2-liter cylinders	11	19	35
78-liter cylinders	11	16	31
60-liter cylinders	11	12	27
26.2-liter cylinders	11	-----	20

Table 2: Flammable domain of vapor cloud of LPG in studied cylinders.			
Variables	**100% LEL**	**60% LEL**	**10% LEL**
107.2-liter cylinders	16	22	66
78-liter cylinders	12	19	57
60-liter cylinders	11	17	49
26.2-liter cylinders	------	11	39

According to the results, in the full gas leaks of 60, 78 and 107 liters cylinders to distance about 20, 27, 31 and 35 meters around the tank respectively, LPG gas concentration is 21000 ppm that is equals lower explosive limit (LEL) of LPG gas. In case of full leakage of gas from cylinders 2 and 26 liters, gas concentration is not equal to lower explosive limit (LEL).

Part 1-3: Modeling the explosion domain of vapor cloud of LPG

The modeling result of pressure wave caused by the explosion of LPG vapor that has been formed under the scenario 1 is presented in Table 3.

Table 3: Domain of explosion of LPG vapor cloud in studied cylinders.			
Variables	**8 psi**	**3.5 psi**	**1 psi**
107.2-liter cylinders	--------	14	82
78-liter cylinders	--------	13	27
60-liter cylinders	--------	13	25
26.2-liter cylinders	--------	12	24

In case of the explosion of vapor cloud caused by a LPG leakage, blast wave pressure in the 26, 60, 78 and 107 liters cylinders respectively, to distance of 12, 13.13 and 14-meter from tanks is 3.5 psi that may cause serious damage. As well as to distances of 24, 25, 27 and 28 meter of cylinders, pressure caused by blast wave is equal to 1 psi which has the power to break the glass. Graphical modeling results of pressure wave caused by the explosion of LPG gas vapor are shown in Figure 3.

Scenario 2: liquefied gas is leaked from valve and is burnt in environment as jet fire

Graphical modeling of thermal radiation caused by scenario 2 at various intervals of gas a canister is shown in Figure 4. In case of jet fire in the cylinders, its length wills over 8 meters and the amount of thermal radiation of the cylinders with the volume of 26, 60, 78 and 107 liters is about 10 kW/m^2, at the distance of 10, 12, 12 and 14 meters from cylinders, respectively. It may cause death within 60 seconds. Up to distances of 12, 16, 17 and 19 meters of tanks, thermal radiation will be equal to 5 kW/m^2 and it may lead to second-degree burn.

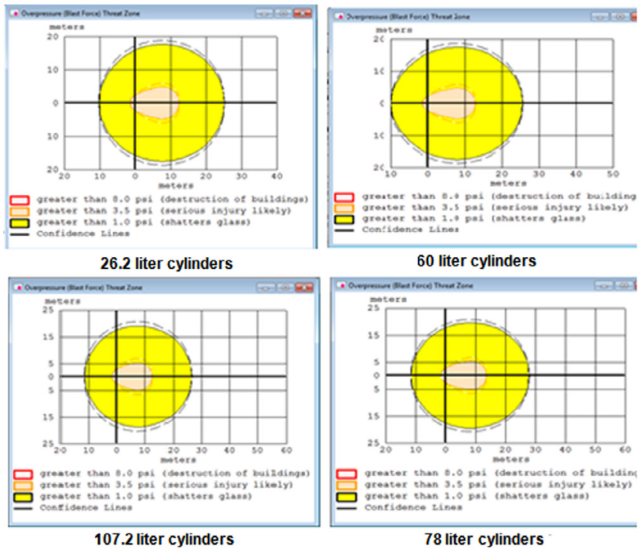

Figure 3: Graphical modeling of blast wave pressure caused by explosion of vapor cloud in the cylinders.

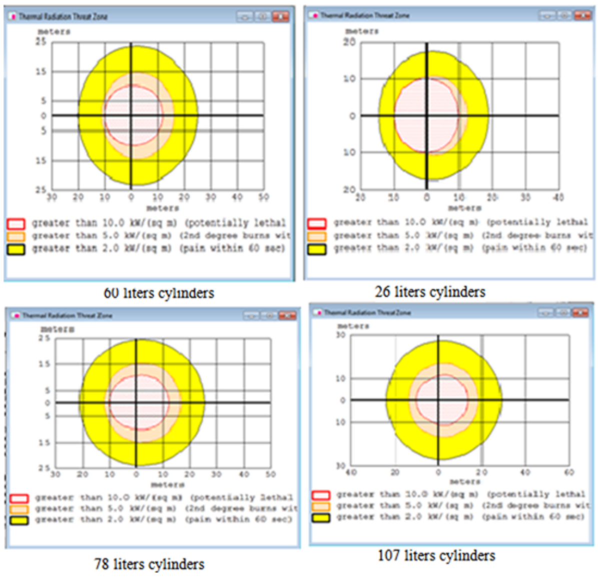

Figure 4: Graphical modeling of thermal radiation at different distances from the cylinders under scenario 2.

Scenario 3: cylinder is exploded and liquid gas is burnt as a fireball (BLEVE)

In the case of scenario 3, in cylinders with the volume of 26, 60, 78 and 107 liters, fireball will occur with a diameter of 14, 17, 19 and 21 meters and within two second. Range of thermal radiation from explosion of expanded vapors of boiling liquid (BLEVE) under Scenario 3 is shown in the Figure 5.

The thermal radiation around the cylinders up to the distances of 39, 48, 48 and 53 meters from them is about 10 kW/m^2 which may cause death of people in the area, and to distances of 55, 68, 68 and 74 meters of tanks, thermal radiation is 5 kW/m^2 and it may lead to second-degree burn.

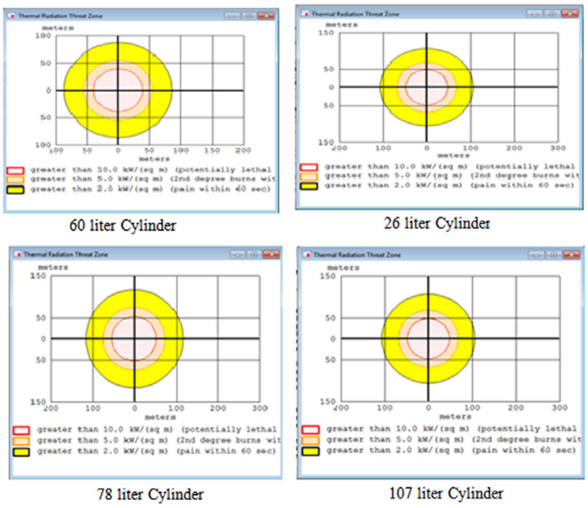

Figure 5: Graphical modeling of boiling liquid expanding vapor explosion (BLEVE) under scenario 3 at different distances of cylinders.

Discussion

According to the results of this study, if the LPG leak from a valve with a hole of 1 inch on cylinders containing LPG gas and release in the environment, approximately in during 1 minute all of containing gas discharge and release in the ambient air. In studied cylinders, with increasing volume of cylinders at distances of 11, 17, 19 and 22 meters from the cylinders, concentration of gas is equals to 60% lower explosive limit (60%LEL) of LPG gas and at a distance of 39, 49, 57 and 66 meters from cylinders, concentration of LPG gas is 2100 ppm and is equal to 10%LEL. LPG vapor at concentrations between 2% LEL and 10% LEL creates explosive combination. [14] As a result, in complete leakage of LPG gas from cylinders, if there is any source of sparks and ignition to a distance of 66 meter from cylinders, blasting will occur. Taking a look at the accident in different parts of the world shows that the slightest negligence in the design, manufacture, and installation, using and keeping the storage tanks of LPG has led to accidents and major disaster. [3] The results showed that up to distance 11 meters around the tank of LPG gas, concentration of gas is 33000 ppm which this concentration can cause severe burns in skin. [14] In case of vapor cloud explosion caused by a LPG gas leakage, it should be noted that blast wave caused by gas leakage in studied cylinder in any distance is not more than 8 psi (that is amount of required pressure for the demolition of buildings). Given that the actual capacity of cylinders with expressed length and diameter is more than actual volume of liquefied gas that is expressed in their catalog and with this amount of gas, only 65% of tank to be filled. If in real more than 65% of cylinders is to be filled, modeling results will be different. Usually in studies about process risk analysis, probability of vapor cloud explosion is considered 0.6 and sudden fire equal to 0.4. [6,15]

In case of jet fire under scenario 2 in examined cylinders a fire with length of 8 meters will be created that amount of its thermal radiation for of 26, 60, 78 and 107 liters cylinders respectively, at 10, 12, 12 and 14 meters of cylinders is about 10 kW/m^2 that may cause death within 60 seconds and to distances of 12, 16, 17 and 19 meters of tanks, thermal radiation is equal to 5 kW/m^2 and it may lead to second-degree burn. Also to distances of 19, 25, 26 and 29 meters of capsule amount of thermal radiation is 2 kW/m^2 and it may lead to local pain in during 60 seconds.

Graphical output of ALOHA software indicates that in the case of scenario 3 in 26, 60, 78 and 107 liter cylinders, fireball will occur with a diameter of 14, 17, 19 and 21 meters and within 2 seconds.

In case of BLEVE under scenario 3, amount of its thermal radiation for of 26, 60, 78 and 107 liters cylinders respectively, at 39, 48, 48 and 53 meters of cylinders is about 10 kW/m^2 and it may cause death of people in the area. At distances of 55, 68, 68 and 74 meters of tanks, thermal radiation is 5 kW/m^2 and it may lead to second-degree burn. At distances of 46, 86, 106 and 116 meters of tanks, thermal radiation is 2 kW/m^2 and it may lead to local pain.

The results of this study show that an emergency response plan is necessary. As the estimating the number of people at risk is the first step in determining the need for evacuation. [16], it is recommended to determine the number of residents exposed to the gas in different scenarios.

The strengths of this study are the novelty of this study and use of a simple and reliable software method at different stages of risk analysis. Inability to use the data from this study in all seasons is the limitations of this study. Since this study was conducted in spring, danger intervals may vary in the winter and summer. The results of the study Mortazavi et al, in assessing the release of chlorine gas from storage tanks in order to develop emergency response plans in the petrochemical industry, confirms this matter. [16] Increasing the risk intervals in summer than in winter is due to the fact that, in summer, the temperature of surface layers of the atmosphere near the Earth's surface is almost equal with the temperature of upper layers of the atmosphere and so the atmosphere is more stable than in winter. [17]

The study was carried out only in modeling the amount of gas leaking from the tanks valve outlet, but in practice, sources of emissions in addition to storage tanks, are in other stages of the transfer and application, too. So to identify and control sources of emissions is required to examine the more precise and more detailed. As a result, it is very necessary to carry out further studies in this field. In this study were investigated three main scenarios. It is necessary to identify other scenarios and determine the level of urgency for each of them.

Analysis of large process accidents has shown that a large part of damage and loss caused by accidents, not only are preventable but also is predictable, and providing the measures such as identification of root causes and their ultimate consequences and measures to control them on time is so important. [14] Analysis of root causes of accidents such as release of flammable and explosive chemicals in the environment is one of the most critical steps to increase the level of safety in existing units or at design stage of processes. [18] The risk of extreme events is an important criterion for decision making and precise quantification of risk.

In recent years, studies have been done not only to prevent the occurrence of extreme events, but also reduced their severity.[6] and so the most prevention and control to be carried out on possible scenarios of accidents with lowest cost. Many accidents occur because of corrosion and decay of equipment's body.

Conclusion

For future studies, it is proposed the simulation of the final events of the explosion, and suddenly fire erupted for an accurate estimate of the amount of human and financial losses incurred as a result of incidents and quantitative estimation of the risk of accident by means of comprehensive methods such as risk assessment. Implementation of quantitative risk assessment (QRA), evaluation of the role and effectiveness of barriers against gas leaks, obstacles to the ultimate consequences caused by a gas leak and calculate the probability of failure of the obstacles could achieve more realistic results. The results of the proposed studies with the results of this study may provide a more accurate decision-making ability to manage safety risks.

Conflict of Interest

All authors disclose that there was no conflict of interest.

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