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QUANTITATIVE RISK ASSESSMENT IN LPG STORAGE AREA FOR DIFFERENT FIRE SCENARIOS

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ABSTRACT

The Risk Assessment is an important legal requirement which should be carried out in industries in order to prevent any incident in future and manage emergencies better. In this article a typical LPG (Liquefied Petroleum Gas) storage bullet of capacity 14.7m^3 and truck tanker of capacity 18 m^3 were selected for the study. Risk assessment was carried out for various fire scenarios such as BLEVE, VCE, and Jet fire which can happen in LPG storage area. The inputs used in the estimation are collected from various articles and from a typical LPG handling and storing industry in the southern part of Tamil Nadu. The meteorological conditions for the assumed Madurai region are given as an input data in the ALOHA software for dispersion predictions of various scenarios. The accident situations are selected from various reports and literatures of LPG storages around the world. By using the ALOHA software, the dispersion models are used to estimate dispersion concentrations, Blast effects, Flammable effects, Thermal radiation and Toxic effects. The results are arrived from the predicted and user defined inputs in ALOHA software with the references and industrial investigations.

Keywords: LPG, Risk assessment, BLEVE, VCE, Jet fire, ALOHA, Thermal radiation effects, Dispersion and explosion effects and Dispersion and toxic effects.

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1. INTRODUCTION

Chemicals are highly hazardous in nature. Starting from storage of raw chemicals to the packaging of finished products chemical pose a threat to human life and health [1]. LPG is the material which produces heat on combustion and stored in industries for the production of heat energy. LPG is one of the highly hazardous and volatile substancesin nature. It is a widely used chemical in industries and has potential for damaging the environment. It requires proper safety measures in order to store and use safely [2][3]. The dispersion modelling can be employed in any manufacturing organization which involves production and use of chemicals that pose threat to people and property due to accidental leakage and fire. It provides a way to manage hazardous chemical storages in manufacturing sectors [4]. Incidence of chemical leakage presents a severe threat to the safety of residents in close proximity, air quality and occupational safety. The prevention and simulation of chemical leakage has become one of the most important topics in the fields of environmental protection and process safety [5-33].

Throughout the world risk assessment is gaining importance nowadays and governments have insisted the industries strictly to conduct risk assessment by various act and rules [6]. For instance, 'The Chemicals Control Act of Korea' which was enacted in 2015, requested industrial sites which use chemicals to perform a risk assessment for all chemical facilities and to distribute the results to the local residents and governments. Thus to maximize the safety of many local residents and to prepare for chemical accidents, risk assessments should be conducted using a variety of risk assessment programs and the worst-case damage radius should be determined with the guidelines framed in the Korean chemicals control act [7]. According to guidelines from Indian government, it is mandatory to perform a risk assessment by a competent person which must be attested and filed by chief inspector of factories. It is the UK's law under section-3 in the Management of Health and Safety at Work Regulations (MHSWR) that every employer and self-employed shall carry out a risk assessment of any risks to the health and safety of employees or other persons.

Risk assessment is a technique where the Identified hazards are evaluated to determine the potential cause of an accident and further to reduce to the lowest reasonable risk level to protect worker's health and safety. It can be categorized into Qualitative and Quantitative risk assessment which is being carried out using different techniques. ALOHA (Aerial Locations of Hazardous Atmosphere) is user friendly open source software developed by United States Environmental protection agency (US-EPA) and NOAA (National Oceanic and Atmospheric Administration). It allows the user a choice of several accident scenarios and makes use of appropriate source algorithm to inject material into the air over a limited time. Using ALOHA any case study with any condition and situations can be arrived with the detailed dispersion models. It can also estimate the threat zones associated with several types of hazardous chemical releases including toxic gas clouds, fires and explosions. The source emission time may vary between limits of one minute to one hour. A flat, homogeneous earth has been assumed for assessing the different hazardous chemical release in the dispersion model. It is also used to simulate the model to analyse the impact due to leakage from the various potential accidents [8][9].

The identification of risks and hazards in the storage tank is feasible with the help of Failure Mode and Effects Analysis. FMEA is a technique to identify the prioritised risk factors associated in the LPG storage area. It is a systematic 'bottom-up' method of identifying single failure modes and failure probabilities of a system, item, function or piece-part, by determining the effects of a failure mode on the next higher level of the design. In FMEA, risk priority number (RPN) is determined by multiplication of scores that are inferred from the degree or probability of occurrence, severity and ease of detection of the problem, without taking into consideration the relative importance of factors [10].

2. METHODOLOGY

The storage of chemicals are highly risky and hazardous in any industries which requires safety guidelines to be followed for its safer containment [11]. Thus it is mandatory to know about the properties of any chemical that are stored in any premises. The safe and prevention methods must be practised as the storage accidents cause fatalities in the surroundings. In this study results have been achieved by using FMEA approach and ALOHA software. A FMEA spread sheet was prepared by using the guidelines given in 'IS-11137 (Part 2): 2012 Analysis Techniques for System Reliability-Procedure for Failure Mode and Effects Analysis (FMEA)' and'IS-15550:2005-Failure Mode Effects Analysis standards for its design and guidelines' [12] [13]. The causes and accident preventive methods are arrived from the fishbone diagram [14] made for a typical study of storage tank accident. The major accident sources or inducers identified in the study such as operational errors, equipment or instrument failures, lightning, static electricity, maintenance error, tank crack or ruptures, piping rupture, operation, management etc., were used in the software as failure modes or causes for the dispersions to occur [14]. The simulation of dispersion and effects of Boiling Liquid Expanding Vapour Explosion, Vapour Cloud Explosion and Jet fires accidents were carried out using these data.

2.1. DATA USED FOR RISK ESTIMATION

The ALOHA modelling of dispersion is carried out by considering a single storied building located at Madurai (9.9^{0}N 78.1^{0}E) with the elevation of 131 m, Tamilnadu, India. The atmospheric condition for the wind was chosen as North-North East direction above 3m from the ground at the speed of 1.38 m/s. The ground roughness was taken as open country and partly cloudy.

2.2. LPG STORAGE DETAILS

The chemical used was assumed to be LPG of Molecular Weight: 44.10 g/mol, Ambient boiling point: -44.2 0F and Freezing point: -305.8 0F. The temperature of air and internal storage temperature was taken as 37.2^{0}C with 50% of relative humidity. The Table-1 shows the dimensions of typical tanker and bullet used in the risk estimation. Assuming Tanker and bullet as cylindrical shapes, volume of tanker and bullet have been arrived.

Table 1 Dimensions of Tanker and Bullet

Description	Tanker	Bullet
Diameter (m)	2.2	2.2
Length(m)	4.74	3.87
Volume (m^3)	18.0	14.7

The LPG storage tank data used in this study was referred from the various articles and LPG storages from manufacturing industries. For the study the storage chosen was bullets of capacity 14.7 m^3. LPG Stored in the bullet was assumed to be filled up to 97% of its capacity and was assumed to be above ground level. The bullet pressure was around 2kg/cm^2(28.4467 psi). The tanker of maximum 18MT capacity was chosen for the study and assumed to be filled using flexible hoses from the bullet.

2.3. DAMAGE CRITERIA

A flammable chemical either in the form of gas or liquid if it gets ignited creates thermal radiation effects around the area of burning. A large fire may cause fatality or injuries of different degrees of burn. The severity of a burn injury depends on the time duration of such exposure. The Table-2below shows the critical radiation intensity levels for duration of 10 seconds, which can cause various degrees of injury and was taken from the ALOHA software [15].

Table 2 Damage Criteria for Heat Radiation

Incident Flux (kw/m^2)	Damage
37.5	100% Fatal, Process equipment is damaged
25.0	100% Lethal/ Fatal, Minimum energy required to ignite wood
10.0	Potentially lethal within 60 seconds
5.0	Second degree burns within 60 seconds
2.0	Second degree burns within 60 seconds
1.6	No discomfort for long exposure

3. RESULTS AND DISCUSSION

3.1. Thermal Radiation of BLEVE

Boiling Liquid Expanding Vapour Explosion abbreviated as BLEVE is a physical explosion which occurs when storage vessels are exposed to external and lasts for a few seconds, and could be of an accident of very high intensity. The effects caused due to bullet BLEVE was shown in Figure-1 and tanker BLEVE was shown in Figure-2.

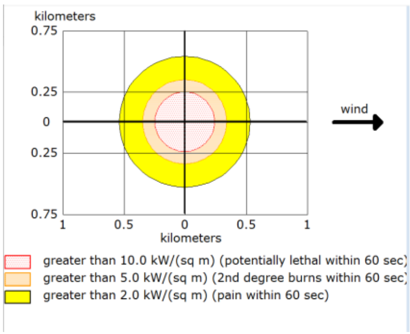


Figure 1 Bullet BLEVE

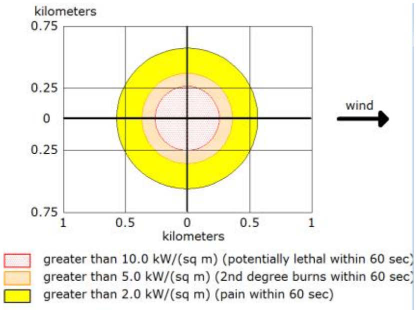


Figure 2 Tanker BLEVE

Table-3shows the outputs arrived for the Bullet and Tanker BLEVE.

Table 3 Thermal Radiation due to BLEVE

Source	Volume (m^3)	Fireball Duration (sec)	Fireball Diameter (m)	Thermal Radiation levels		
				10 (kw/m^2) for radius of	5 (kw/m^2) for radius of	2 (kw/m^2) for radius of
Bullet	14.7	8	109	243 m	343 m	535 m
Tanker	18	9	117	259 m	366 m	570 m

From the above figures and table, it is found that the heat radiation effects due to tanker BLEVE is much higher when compared to bullet BLEVE. This may be due to the higher volume of LPG stored in the tanker than the bullet. The radiation levels for the BLEVE are provided in the table 3.

3.1.2. Jet Fire

The other cases of fires include jet fires that generally create localized effects. This can happen due to the release of flammable liquids confined or spread in the form of a liquid jet. After catching fire by the external forces, this burns as a jet and radiates heat around. TheFigure-3represents the bullet jet fire and Figure-4 shows the tanker Jet fire heat radiation levels considering short pipe/valve opening of rectangular shape having length 15 cm and width of 5 cm at the middle of the tank. The jet is assumed to be ignited by external sources.

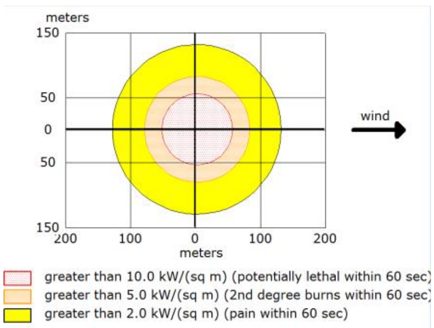


Figure 3 Bullet Jet fire

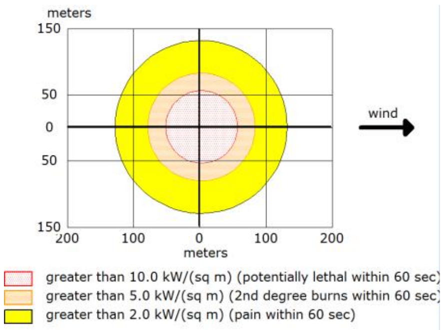


Figure 4 Tanker Jet fire

The below Table-4 shows the outputs arrived for the tanker and bullet jet fires.

Table 4 Thermal Radiation due to Jet Fires

S.No	Source	Maximum Burn rate (kg/min)	Flame Length (m)	Duration (sec)	Thermal Radiation levels		
					10 (kw/m^2) for radius of	5 (kw/m^2) for radius of	2 (kw/m^2) for radius of
1	Bullet	3920	40	120	58 m	84 m	133 m
2	Tanker	3920	40	180	58 m	85 m	133 m

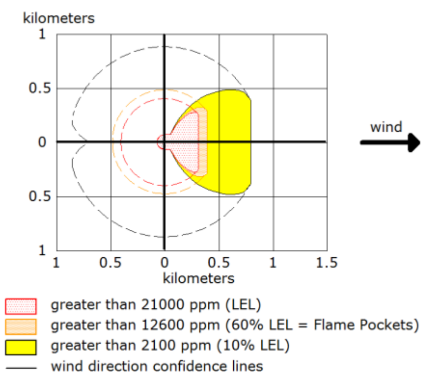
From the table, we can infer that the tanker and bullet are equally hazardous in case of jet fire. Both tanker and bullet make a jet fire for the length of 40 m which is lethal potential and having duration of 2-3 minutes for complete burning of all the LPG.

3.2. Dispersion and Flammable Effects

Vapour cloud explosions (VCE) are capable of creating great impact on the plant and surroundings. Vapour cloud explosions produce pressure waves. The effect of VCE depends on the peak incident over pressure due to pressure waves and the duration of the maximum overpressure. The vapour cloud can travel with the wind flow if it was not ignited. So the Vapour clouds are also hazardous once they reach the neighbourhood. Table-5 provides the damage criteria for vapour cloud explosions (from ALOHA). The flammable threat zones caused due to Vapour Cloud explosion for Bullet and Tanker are shown in Figure-5 and Figure-6 respectively.

Table 5 Damage Criteria for Vapour Cloud Explosions

Peak Overpressure (bars)	Extent of Damage
0.02	10% of glasses broken
0.10	Shatters glass
0.20	Shattering of concrete block walls; distortion of steel frames and others pulling away from foundations
0.24	Serious injury
0.56	Destruction to buildings
0.68	Heavy machinery movement and bad damage



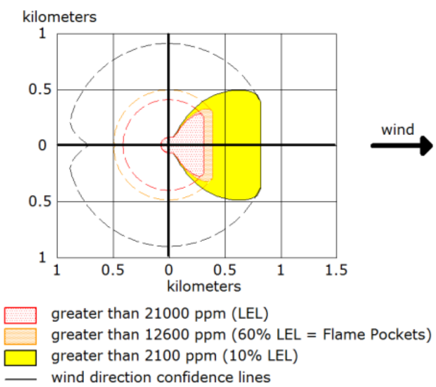


Figure 5 Bullet Flammable Threat Zone **Figure 6** Tanker Flammable Threat Zone

The Table-6 shows the flammable threat zones for the tanker and bullet Vapour Cloud flammable effects.

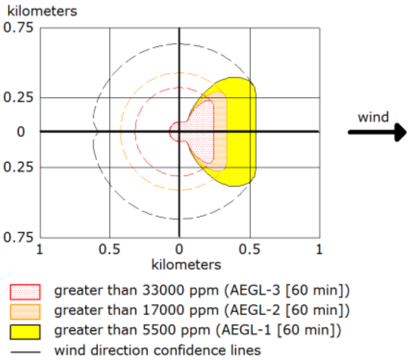
Table 6 Flammable threat Zone of Vapour Cloud

S.No	Source	Volume (m^3)	Maximum Avg. Release rate (kg/min)	Duration (Sec)	Flammable		
					100% LEL up to the distance of	60% LEL up to the distance of	10% LEL up to the distance of
1	Tanker	18	3810	180	312 m	394 m	822 m
2	Bullet	14.7	3770	180	311 m	389 m	792 m

The release rate in the tanker was higher due to higher volume. Thus the clouds of chemical vapour will be formed quickly with higher mass when compared to bullet leakage. These Vapour Clouds can cause damages and lethal to the living beings when ignited as the lower explosive limit are available within the radius of 312 m for tanker and 311m for bullet.

3.3. Dispersion and Toxic Effects

In case of dispersion, if the chemical is toxic instead of flammable the effects of dispersion are far reaching. Therefore it will be equally damaging as the persons exposed to various levels of concentrations depending upon the toxic characteristics of the chemical. The degree of toxic hazard depends on the factors of exposure duration, cloud concentration and gas toxicity. The Figure-7 shows the toxic vapour concentrations around the area of bullet and Figure-8 shows the toxic vapour concentrations around the area of tanker.



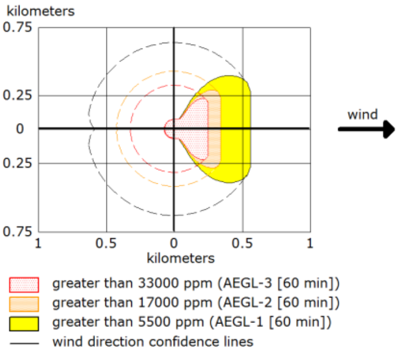


Figure 7 Bullet Toxic area of Vapour cloudFigure-8: Tanker Toxic area of Vapour Cloud

The below Table-7 shows the outputs arrived for the tanker and bullet toxic Vapour Cloud.

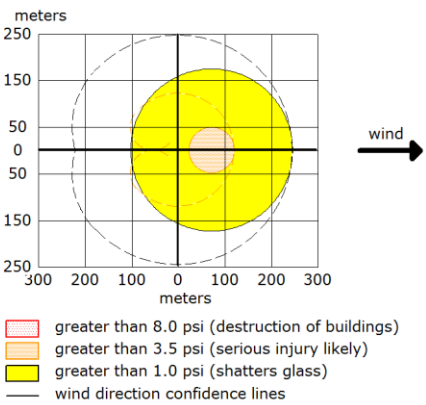
Table 7 Toxic Effects due to Vapour Clouds

S.No	Source	Volume (m^3)	Duration (sec)	Toxic level distance		
				AEGL-1 up to the distance of	AEGL-2 up to the distance of	AEGL-3 up to the distance of
1	Bullet	14.7	180	547 m	341 m	248 m
2	Tanker	18	180	561 m	345 m	250 m

The toxic threat zones obtained are different from the threat zones of fire situations. The AEGL (Acute Exposure Guideline Level) provides the hazardous levels of chemical concentrations and the above levels of chemical concentration were estimated through ALOHA. It was found that the LPG was hazardous when released, as the final level of AEGL-3 was generated. The LPG toxicity level was found to be up to a distance of 547m for the bullet and 561m for the tanker. It can cause suffocation to people at a very short interval of time as toxic level reaches within duration of 3 minutes.

3.4. Dispersion and Blast Effects

The leakage due to a small opening was assumed for the tanker and bullet vapour cloud blasts. The rectangular opening was considered in this case. The area for the opening was taken as 15 cm length and 5 cm width. The leakage through the opening was assumed to be happened in a short pipe/ valve. The ignition was assumed to be happened after 2 minutes of leakage by a spark or flame. The blast area of overpressure was modelled in the Figure-9 for bullet VCE and Figure-10 for tanker VCE respectively.



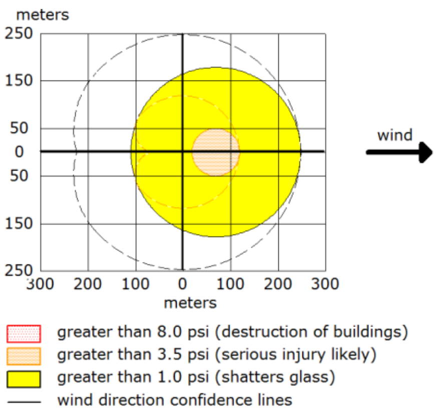


Figure 9 Bullet Vapour Cloud ExplosionFigure-10: Tanker Vapour Cloud Explosion

The Table-8 shows the blast over pressure zone arrived for the tanker and bullet Vapour Cloud Explosions.

Table 8 Blast over pressure zone due to Vapour Cloud Explosion

S.No	Source	Volume (m^3)	Time of ignition after release (sec)	Blast Over pressure zone		
				8.0 psi up to the radius of	3.5 psi up to the radius of	1.0 psi up to the radius of
1	Bullet	14.7	120	---	121 m	246 m
2	Tanker	18	120	---	119 m	248 m

From the table and the figures it was inferred that the bullet and tanker are relatively hazardous as they cause serious injury and shattering of glasses when the vapour cloud gets exploded. The effects will be high upto radius of121mfor bullet and 119 m for tanker.

4. CONCLUSIONS

From the results it was found that the BLEVE in tanker and bullet are highly hazardous. It takes about 10 seconds to generate a complete fireball of radius 117 m in tanker and 109 m in bullet. Jet fire effects are invariably confined to any industry premises. The jet fire after ignition takes 2-3 minutes for the complete completion of fuel burning. The jet flame length was estimated to be 40 m in length for both tanker and bullet. BLEVE and VCE can create offsite emergency situations. The second stage of serious effects for all the scenarios cross the factory boundary and could cause damage beyond the premises of factory. Vapour clouds and its explosion can occur in 3 minutes. It can cause 312 m of highly concentrated flammable threat zone for tanker and 311 m for bullet. The toxic effect was also risky as it causes suffocations for a distance of 561 m for tanker leakage and 547 m for bullet leakages due to a rectangular opening of 15x5 cm at the centre location of both storages. The blast area can cause a severe injury and shattering of glasses when the vapour clouds get ignited due to external ignition sources which can travels along the wind directions. The vapour cloud explosion cannot be easily controlled as it is totally depends on the weather conditions. The effect of toxic gases prevails for about 1 hour around its surroundings. It is therefore, imperative on the part of the storage area to be alert as for as the handling of LPG is concerned. Open land with plantation with a wide green belt must be planned around premises, in order to reduce the effects of any off-site risk. The Typical Plant/ industry needs to take extreme care as far as the safety of its surroundings and operations are concerned, which could be seen in the earlier sections. Based on the above results the safer distances between the LPG storages and the buildings, operational units, tanker/trucks can be evolved and compared with Static Mobile &Pressure Vessel Rules framed under Indian Explosives act 1884.Also during siting and layout design of LPG storages safe distances can be predicated using the ALOHA dispersion model. In addition the industries should also strictly prepare the emergency plan and periodically conduct emergency drills as a precautionary measure.

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