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Research Article

Evaluation of Bleve Impacts from LPG Spherical Tank by Aloha

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Abstract

Refineries produce Liquefied Petroleum Gas (LPG) and store the LPG in cylindrical or spherical tanks. If the LPG tanks are exposed to a fire of sufficient duration and intensity, they can undergo a Boiling Liquid Expanding Vapour Explosion (BLEVE). A BLEVE is an extremely powerful explosion. BLEVE gives rise to the following effects: (1) blast wave, (2) fireball, and (3) fragments. The world has witnessed many BLEVE incidents. This study aims to evaluate the BLEVE fireball thermal radiation threatening the safety of workers and communities, focusing on the 1000 m^3 LPG spherical tank as a case study. The Areal Locations of Hazardous Atmospheres (ALOHA) program is employed to evaluate the thermal radiation. The BLEVE fireball thermal radiation impacts have been estimated at 10%, 20%, 30%, 40% and 50% of the capacity of LPG – 6. The farthest thermal radiation threat zones are identified in case of half full tank as follows: (i) the potentially lethal red zone extends up to almost one km, the workers and the neighboring community who are outside their offices and shelters will be at risk (ii) the second-degree burns, the orange zone extends up to one and half km, and (iii) the pain yellow zone extends up to two kms.

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KEYWORDS: Liquefied Petroleum Gas, Spherical Tank, Boiling Liquid Expanding Vapour Explosion, Fireball, Thermal Radiation, ALOHA.

INTRODUCTION

Liquefied petroleum gas (LPG), also referred to as liquid petroleum gas or commonly as propane and butane, is a combustible mixture of hydrocarbon gases widely utilised as a fuel for heating systems and transportation. Approximately 60% of LPG is derived from the extraction of natural gas and crude oil, while the remaining 40% is obtained as a byproduct of crude oil refining processes [1]. Within refineries and gas processing facilities, LPG is stored in pressurised containers, which are typically designed as either cylindrical or spherical tanks. These storage vessels are generally constructed from steel or other robust materials capable of withstanding the high pressures and low temperatures necessary to maintain LPG in its liquid state.

According to Lopez [2], LPG storage tanks can be classified into various types, with spherical vessels being particularly suitable for high-pressure storage. The spherical configuration offers significant structural strength due to the uniform distribution of stress across its internal and external surfaces, minimising the likelihood of weak points. However, the spherical tanks are more expensive to manufacture compared to cylindrical or rectangular alternatives. Despite this, they provide an important advantage as their surface area relative to volume is lower than that of other shapes. Consequently, heat transfer from the surrounding environment to the stored liquid is reduced, making spherical tanks more thermally efficient [3].

A BLEVE occurs when a pressurised vessel containing a flammable liquid is exposed to intense heat, causing the material to weaken and ultimately rupture. This type of explosion produces several hazardous effects, including a blast wave, a fireball, and the projection of fragments. BLEVE incidents are considered among the most destructive industrial accidents, often resulting in significant loss of life and extensive property damage [4]. Numerous incidents worldwide have been associated with the storage and handling of LPG.

The present study aims to evaluate the consequences of a BLEVE event involving a 1,000-meter-cube LPG spherical storage tank. The ALOHA software has been employed to estimate the potential impact of such an incident. The findings of this research may offer valuable insights and recommendations for the planning and layout design of similar storage facilities.

Hazards from LPG

LPG is a widely used and essential fuel in both domestic and commercial applications. Despite its importance, it presents considerable hazards as leakage can lead to fires or explosions. Due to its ability to be compressed at relatively low pressure, LPG is typically stored in liquid form within pressurised tanks and vaporised before use. A single unit volume of liquid LPG can expand into approximately 245 to 275 units of vapour. Additionally, LPG possesses a heating value that is approximately 2.5 to 3 times greater than that of natural gas, indicating that a substantial amount of energy is stored within a relatively small volume.

Furthermore, a vapour cloud explosion (VCE) may occur if ignition is delayed and the flame propagation velocity increases. The consequences of such incidents depend on factors such as the size of the leak and the timing of ignition. In the case of small leaks, BLEVE generally represents the worst-case scenarios in terms of maximum impact distance, regardless of whether ignition is immediate or delayed. Conversely, for larger leaks or complete ruptures, flash fires or VCEs resulting from delayed ignition may produce the most extensive impact range.

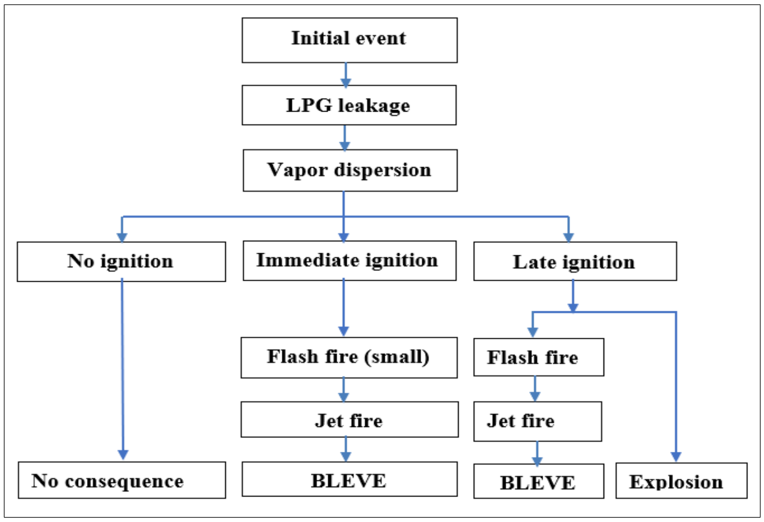


Fig 1: Event sequences of LPG leak [5].

BLEVE

The Centre of Chemical Process Safety [6] defines BLEVE as an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at atmospheric pressure. Similarly, CCPS [7] describes BLEVE as the sudden release of a large quantity of pressurised superheated liquid into the atmosphere. This phenomenon typically occurs when a vessel containing a superheated liquid, such as propane, undergoes catastrophic rupture, most often due to exposure to an external fire, such as a pool fire beneath the vessel or a jet torch fire directly impacting its surface. During such exposure, the vessel experiences an increase in internal pressure, causing the pressure relief valve to open and release vapour. As the liquid level inside the vessel decreases, the portion of the vessel wall above the liquid level becomes directly exposed to flames. Because vapour provides relatively poor heat transfer compared to liquid, this section of the wall heats up rapidly. As a result, the material weakens, eventually leading to rupture and sudden vessel failure.

In addition to fire exposure, BLEVE incidents may also result from other causes, including mechanical damage, corrosion, overpressurisation, or material defects [8, 9]. According to Birk [10] and Shaluf [11], BLEVE events can be categorized into three types: BLEVE, hot BLEVE, and cold BLEVE, depending on the underlying mechanism and conditions. Any system involving significant quantities of liquefied gases, volatile superheated liquids, or gases at high pressure and temperature can be considered susceptible to BLEVE.

The development of a BLEVE typically progresses through several stages, as illustrated in Figure 2, which outlines the mechanism of BLEVE formation [12, 13].

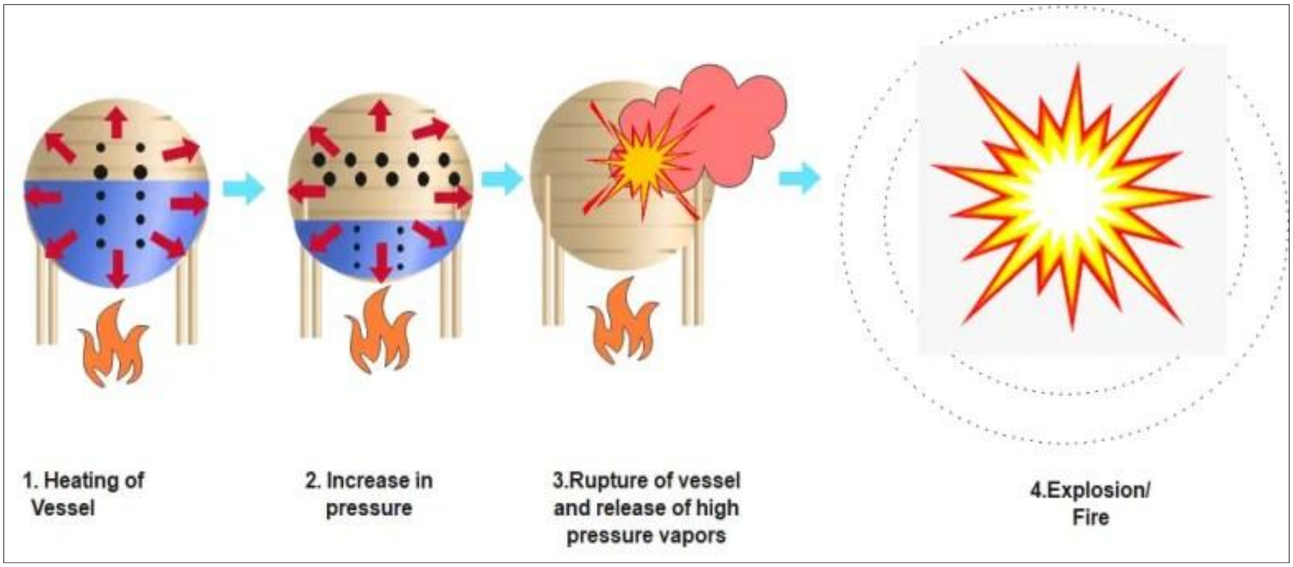


Fig 2: Mechanism of BLEVE [12].

The Consequences of BLEVE

A BLEVE event produces several significant hazardous effects. These include: 1. An overpressure blast wave resulting from the rapid expansion of the superheated liquid. 2. Intense thermal radiation in the form of a fireball caused by the rapid combustion of the released flammable substance, and 3. the projection of vessel fragments, which may act as high-velocity missiles. Such events have the capacity to cause injuries and considerable damage to facilities, even at substantial distances from the point of origin.

BLEVE Incidents

Numerous major accidents involving BLEVEs have been recorded worldwide. Among the most severe are the incidents at Feyzin and Mexico City. The Feyzin disaster occurred at an LPG storage facility in France consisting of eight spherical tanks containing propane and butane. On 4 January 1966, a leak developed in a propane storage sphere, leading to one of the most serious LPG-related accidents. The event resulted in 18 fatalities and approximately 80 injuries. In total, five spherical tanks and two additional pressure vessels ruptured while three others sustained damage [14].

Another catastrophic event took place at the PEMEX LPG terminal in San Juan Llhuicatpec, Mexico City. This facility received daily supplies from three gas refineries. On 19 November 1984, four LPG spheres, each with a capacity of 1,500 m^3, along with several smaller cylinders ranging from 45 to 270 m^3, experienced BLEVEs. The explosion caused extensive destruction of the terminal, resulting in approximately 650 deaths and more than 6,400 injuries. The financial losses due to the explosion and subsequent fire were estimated at around $31 million, based on 1984 values [15].

A further incident occurred on 16 July 2015 in Shandong, China, where an LPG spherical tank at a chemical plant developed a leak. This incident led to both a BLEVE and a Vapour Cloud Explosion (VCE). The explosion caused the collapse of nearby structures and resulted in a fire that spread to nine spherical tanks. As a precaution, residents within a five-kilometre radius were evacuated [5]. Table 1 presents a summary of the initiating factors that can lead to BLEVE events [16].

Table 1: The initiating events that trigger BLEVE [16].

Initiating event	Frequency
Fire	36%
Mechanical damage	22%
overfilling	20%
Runway reactions	12%
Overheating	6%
Vapour space contamination	2%
Mechanical failure	2%

Case study

The case study focuses on a refinery equipped with six LPG spherical storage tanks, designated LPG-1 through LPG-6. These tanks are used for storing LPG products. Four of the tanks (LPG1, LPG2, LPG3, and LPG4) are smaller units, each with a storage capacity of 500 m^3. The remaining two tanks (LPG5 and LPG6) are larger, each with a capacity of 1,000 m^3. The arrangement of these tanks and the distances separating them are illustrated in Figure 3.

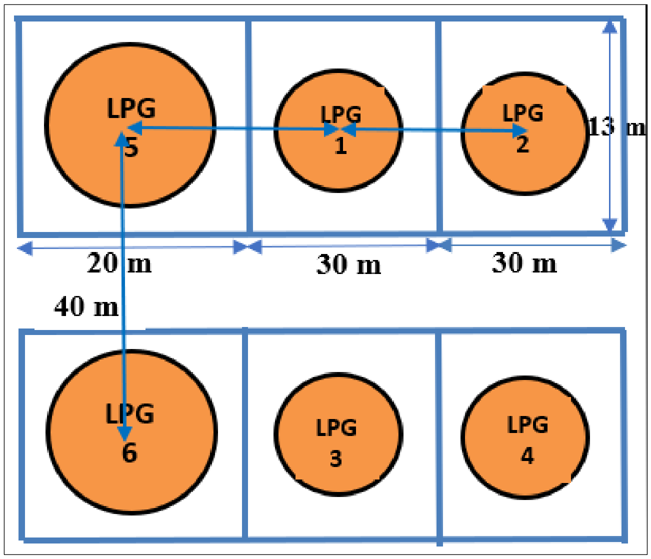
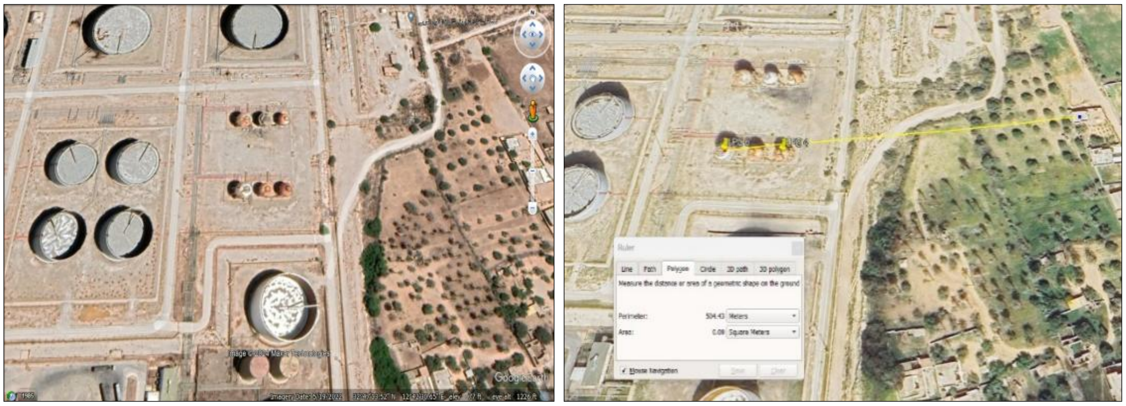


Fig 3: The layout of the LPG spherical tanks

Figure 4 presents an aerial view of the facility obtained from Google Earth, indicating that the distance between tank LPG-6 and the nearest residential area is approximately 504 meters.



Measure the distance or area of a geometric shape on the ground

Perimeter: 504.43 Meters

Area: 0.08 Square Meters

Fig 4: Google Earth aerial view of the LPG spherical tanks, and the distance between the LPG spherical tanks and the housing accommodation

The LPG storage system is equipped with several pipelines, including inlet, suction, transfer, return, balance, circulation, drain, and discharge lines. The inlet line is responsible for supplying LPG to the tank. The suction line facilitates simultaneous operational processes, while the transfer line is used to move LPG between tanks during maintenance activities or emergencies. Return lines are utilised to redirect LPG that does not meet the required specifications. The balance line is designed to transfer excess product to empty tanks in cases of overfilling. The circulation line enables the movement of LPG from the bottom of the tank back to the top to ensure uniform mixing of the contents. This circulation process typically lasts about four hours, after which a sample is collected and tested in the laboratory to verify compliance with required standards before certification for use, such as cooking applications. Additionally, the tanks are fitted with control, safety, and firefighting systems. Gas detection systems are also installed, with four detectors positioned at ground level around the deck perimeter to identify any potential gas leaks. Figure 5 illustrates the LPG's spherical tank and its associated system.

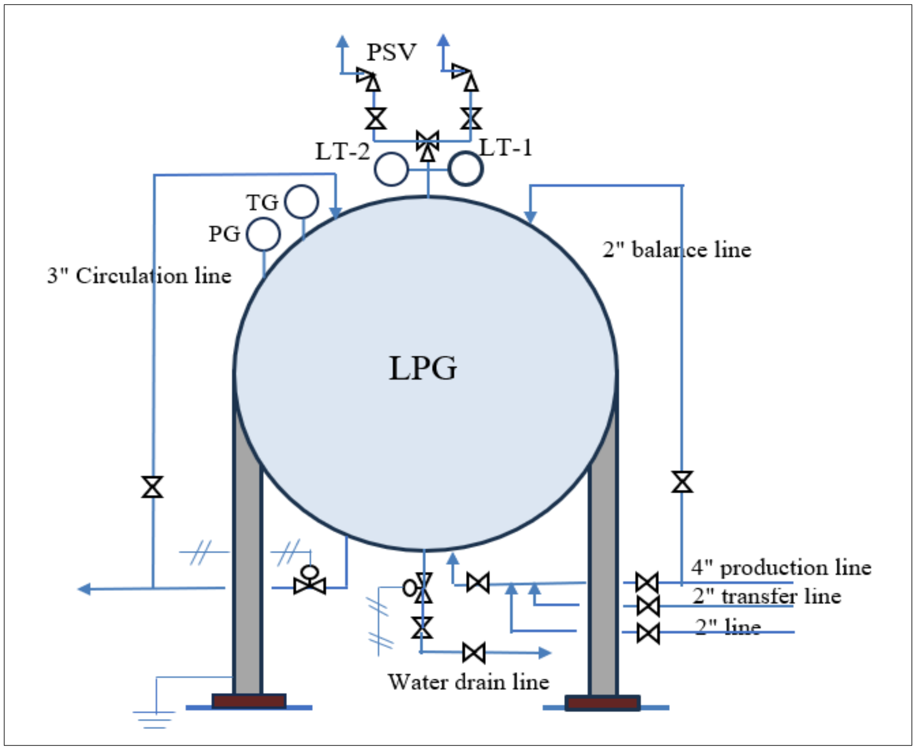


Fig 5: LPG spherical tank

The Characteristics of the LPG spherical tank have been summarised in Table 2.

Table 2: Characteristics of LPG spherical tank

Characteristics	Values
Substance	LPG
Design pressure (kg/m^2)	10
Test pressure (kg/m^2)	15
Operating pressure (kg/m^2)	5.8
Design temperature (C)	80
Operating temperature (C)	35
Volume m^3	1000
Density (kg/m^3)	530

ALOHA

Areal locations of hazardous atmospheres (ALOHA) is a software tool developed collaboratively by the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). It is designed to support emergency planning and response for incidents involving hazardous chemical substances. According to NOAA, the software is capable of evaluating accident scenarios in both terrestrial and marine environments. Although ALOHA is less precise than commercial modelling tools such as PHAST and TRACE (SAFER), it remains a valuable and widely used application [17].

ALOHA is freely available and user-friendly, allowing users to easily perform hazard assessments. Technical support is also accessible through the reporting centre when needed. The program includes an extensive and continuously updated database. Its modelling capabilities incorporate key atmospheric parameters, including wind speed and direction, atmospheric stability, surface roughness, and temperature inversion layers. ALOHA generates rapid predictions that have been validated against other modelling tools and experimental data to ensure reasonable accuracy. However, users are required to have a basic understanding of atmospheric conditions and input parameters. Overall, ALOHA provides significant advantages due to its accessibility, ease of use, and ability to estimate emission impacts effectively [18].

ALOHA Thermal Radiation Estimation Results

The ALOHA software was utilised to estimate the thermal radiation effects of a BLEVE-induced fireball originating from the large LPG spherical tank (LPG-6).

ALOHA thermal radiation impact criteria and threat zones

Table 3 presents the criteria adopted by ALOHA for assessing and categorising the thermal radiation impacts and corresponding threat zones associated with a BLEVE fireball.

Table 3: ALOHA thermal radiation impact criteria (EPA, 2007).

Threat zone	Thermal radiation level (kW/m^2)	Impacts
Red	10	Potentially lethal within 60 sec
Orange	5	2nd degree burns within 60 sec
Yellow	2	Pain within 60 sec.

ALOHA Fireball thermal radiation from LPG - 6

In this analysis, a BLEVE scenario was assumed to occur at varying fill levels of the LPG-6 tank, specifically at 10%, 20%, 30%, 40%, and 50% of its total capacity. The ALOHA output is expressed in terms of thermal radiation threat zones. The model identifies three concentric circular zones: The red (inner) zone indicates the highest hazard level, while the orange (middle) and yellow (outer) zones represent progressively lower levels of risk.

Thermal radiation is assumed to propagate in all directions. However, it extends slightly further in the downwind direction due to atmospheric effects. ALOHA can also be integrated with Google Earth to visually display these threat zones geographically. Figure 6A illustrates the BLEVE fireball thermal radiation zones generated by ALOHA, while Figure 6b shows the corresponding representation on a Google Earth aerial view.

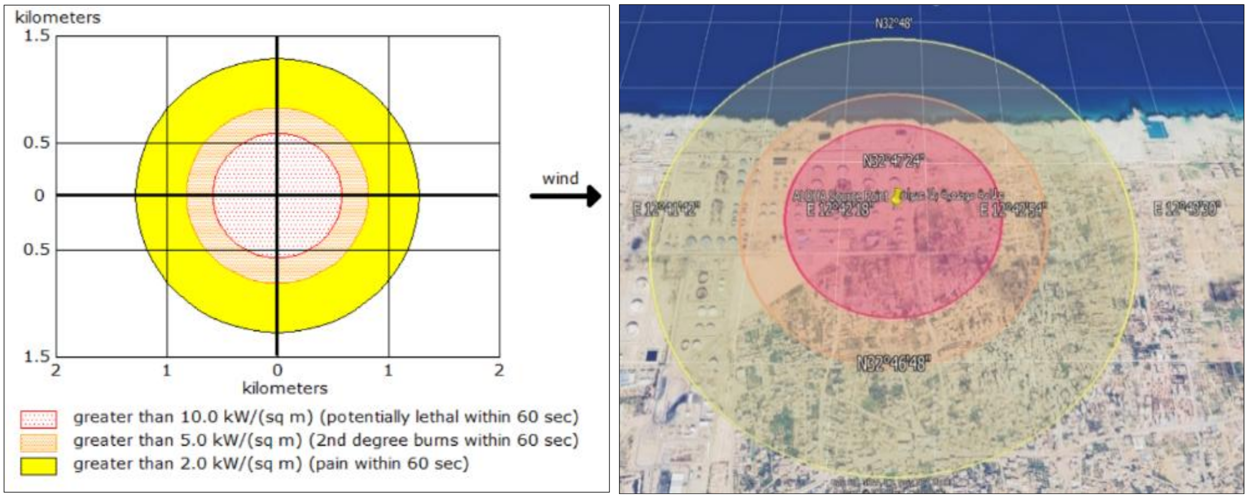


Fig 6: ALOHA BLEVE fireball impact at 10% capacity of LPG tank.

Figure 7 presents the thermal radiation contour for a BLEVE occurring at 20% of the tank capacity.

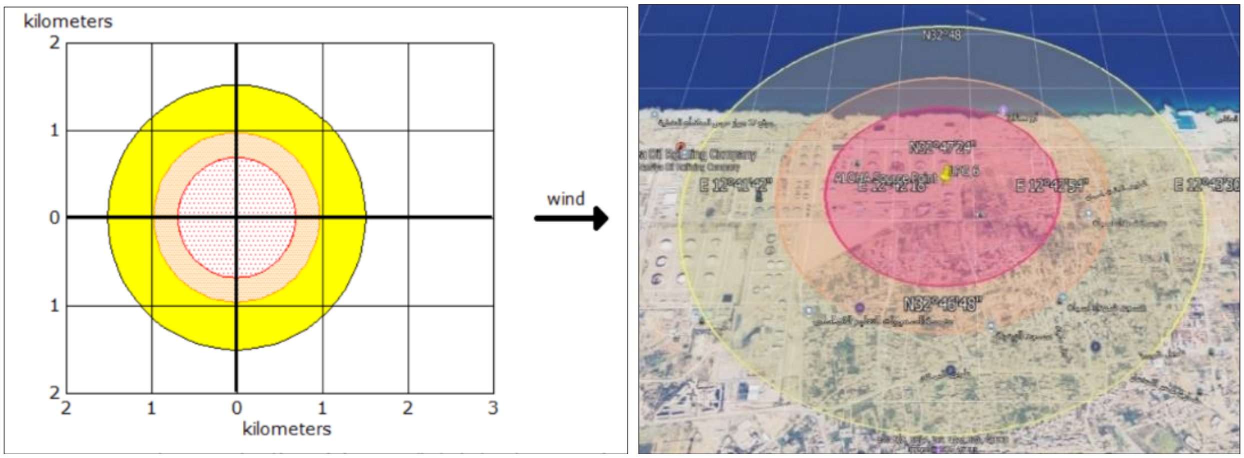


Fig 7: ALOHA BLEVE fireball impact at 20% capacity of LPG tank.

Similarly, Figures 8, 9, and 10 illustrate the thermal radiation contours corresponding to 30%, 40%, and 50% of the tank capacity, respectively.

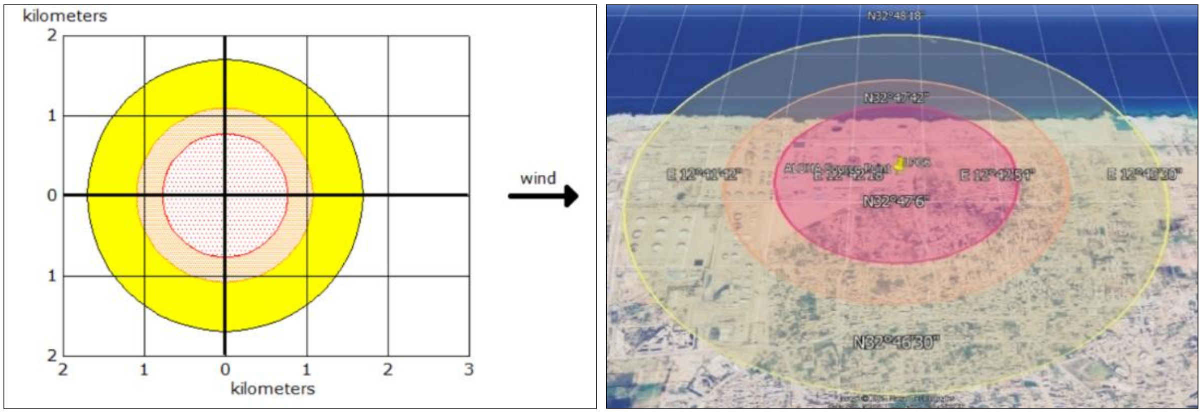


Fig 8: ALOHA BLEVE fireball impact at 30% capacity of LPG tank.

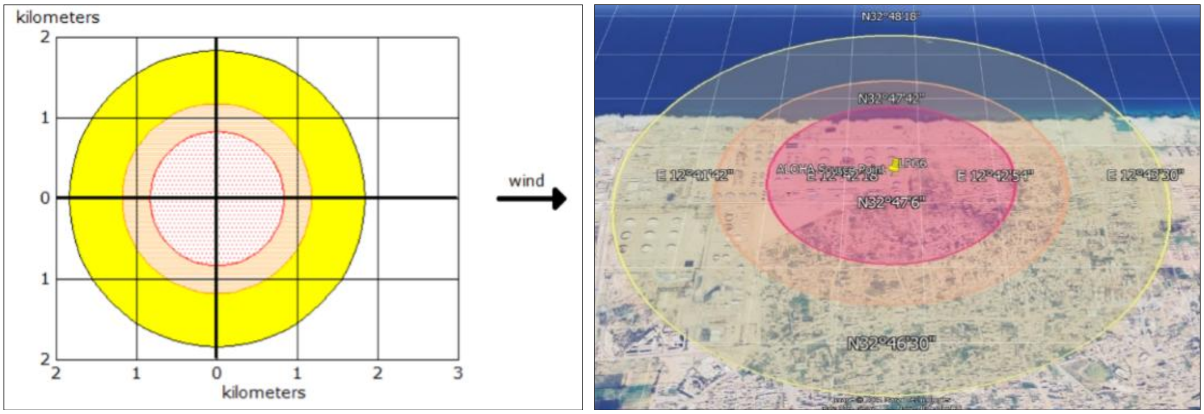


Fig 9: ALOHA BLEVE fireball impact at 40% capacity of LPG tank.

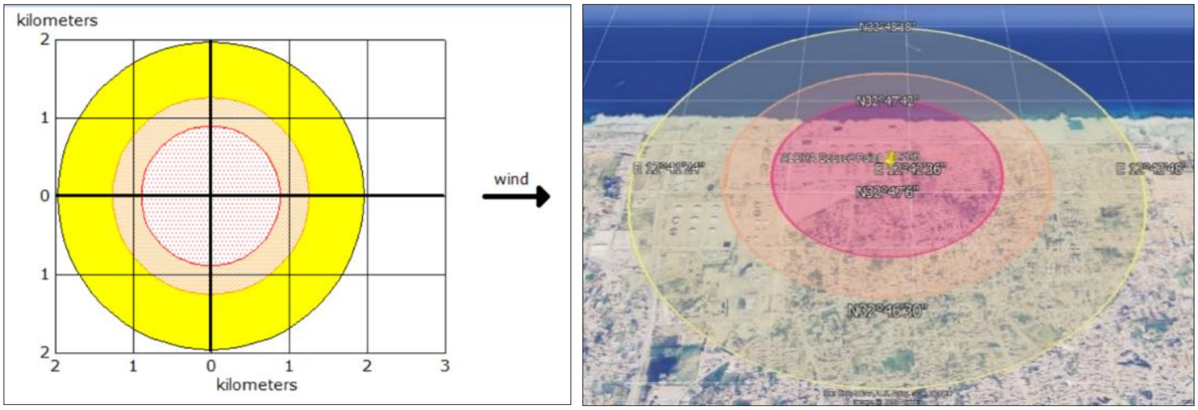


Fig 10: ALOHA BLEVE fireball impact at 50% capacity of LPG tank.

Table 4 summarises the predicted thermal radiation impacts and associated threat zones for the different fill levels of the spherical tank.

Table 4: Summary of BLEVE Fireball Thermal Radiation Threat Zones at Different Tank Filling Levels.

Tank capacity	Threat zone	Distance (m)	Thermal radiation threat
10%	Red	580	Potentially lethal within 60 sec.
	Orange	818	2nd degree burns within 60 sec.
	Yellow	1278	Pain within 60 sec.
20%	Red	688	Potentially lethal within 60 sec.
	Orange	971	2nd degree burns within 60 sec.
	Yellow	1500	Pain within 60 sec.
30%	Red	768	Potentially lethal within 60 sec.
	Orange	1100	2nd degree burns within 60 sec.
	Yellow	1700	Pain within 60 sec.
40%	Red	833	Potentially lethal within 60 sec.
	Orange	1200	2nd degree burns within 60 sec.
	Yellow	1800	Pain within 60 sec.
50%	Red	890	Potentially lethal within 60 sec.
	Orange	1300	2nd degree burns within 60 sec.
	Yellow	2000	Pain within 60 sec.

RESULTS AND DISCUSSION

Although LPG spherical storage tanks are equipped with a circulation system and multiple protective mechanisms, including high-level alarms, pressure control systems, and safety valves, and are subject to regular maintenance, the occurrence of a PLEVE remains one of the most catastrophic events in the chemical process industry.

The study evaluated the extent of thermal radiation damage resulting from a BLEVE-induced fireball originating from LPG storage tank LPG-6. The results are presented in terms of thermal radiation intensity, threat zones and corresponding distances. Outputs generated by the ALOHA model, along with Google Earth visualisations, categorise the affected areas into three zones: red, orange, and yellow. The red (inner) zone represents the highest hazard level, while the orange (middle) and yellow (outer) zones indicate progressively lower levels of risk.

Table 4 summarises the thermal radiation impacts and corresponding threat zones at 10%, 20%, 30%, 40%, and 50% tank capacity. The analysis indicates that at 10% capacity, the lethal thermal radiation zone extends to approximately 0.5 Km in radius. This distance increases with the tank fill level, reaching nearly 1 kilometre at 50% capacity. Although the duration of fireball radiation is relatively short, typically lasting only a few seconds, its effect can be fatal for refinery personnel located outdoors, as well as for nearby residents who are not within protective shelters.

Furthermore, the orange zone, which is associated with second-degree burns within sixty seconds of exposure, extends up to approximately 818 meters at 10% capacity and increases significantly with higher fill levels. At 50% capacity, this zone reaches up to approximately 1.5 Km.

CONCLUSION

The Thermal radiation effects of a BLEVE fireball were assessed at different fill levels (10%, 20%, 30%, 40%, and 50%) for LPG storage tank LPG6. The maximum extent of the thermal radiation hazard was observed at 50% tank capacity. Under this condition, the red (lethal) zone extends to nearly 1 Km, posing a significant risk to personnel working outdoors and to nearby communities. The orange zone associated with second-degree burns reaches approximately 1.5 Km, while the yellow zone, corresponding to pain and minor injury, extends up to about 2 Km.

Although major hazard installations (MHIs), such as refineries, chemical plants, and LPG storage facilities, increasingly utilize advanced simulation software for safety analysis, ALOHA remains a practical and reasonably accurate tool for preliminary hazard assessment. It can support decision-making related to worker safety and assist authorities responsible for communities located near hazardous sites.

To minimise risks, it is recommended that high-risk industries maintain lower inventories of hazardous materials wherever possible and establish comprehensive off-site emergency response plans in coordination with relevant authorities. Additionally, regulatory bodies should enforce appropriate land use planning to prevent residential development in proximity to hazardous installations.

From a design perspective, architectural and civil engineers involved in industrial facility planning should possess a strong understanding of process-related hazards, including fire, explosion and toxic releases. This knowledge is essential for making informed decisions regarding building placement, material selection, safe separation distances, and orientation of critical structures such as control rooms and administrative buildings, ultimately reducing the potential impact of industrial accidents.

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