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# EVALUATION OF BLEVE IMPACTS FROM LPG SPHERICAL TANK

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## ABSTRACT

Major Hazard Installations (MHIs) such as refineries are producing Liquefied Petroleum Gas (LPG). LPG is characterized by an atmospheric boiling point below ambient temperature and therefore stored under pressure in a sphere or a bullet type of vessels. If the LPG tanks are subjected to a fire of sufficient duration and intensity, it can undergo a Boiling Liquid Expanding Vapor Explosion (BLEVE). A BLEVE is an extremely violent explosion that can occur when a vessel containing a pressurized liquid is ruptured. The BLEVE gives rise to the following effects: (1) blast wave, (2) fireball, and (3) fragments. This study aims to evaluate the BLEVE impacts from 1000 $m^3$ LPG spherical tank. The blast wave has been estimated by Trinitrotoluene (TNT) equivalency, Specific Volume, Entropy and Enthalpy (SVEE) and Prugh models. The BLEVE fireball thermal radiation has been estimated through point source model. Mathematical calculations as well as an EXCEL program have been used for the evaluation of the BLEVE impacts. It has been found that the plant facilities as well as the neighboring community buildings will be exposed to blast wave effects up to 400m from the tank. The workers and the residents who live about 400m from the tank will be at risk from thermal radiation if they are outside of their shelters during the incident. 80% of fragments range reaches up to 700m. The BLEVE impacts increases with the increasing of the material released.

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**Keywords**: Liquefied Petroleum Gas, Boiling Liquid Expanding Vapor Explosion, Blast wave, Fireball, Fragments.

# تقييم تأثيرات انفجار بخار سائل متمدد مغلي من خزان غاز البترول المسال الكروي

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**الملخص**

تُنتج المنشآت الخطرة الكبرى مثل مصافي النفط غاز البترول المسال (LPG) وحيث يتميز غاز البترول المسال بانخفاض درجة غليان اقل من درجة حرارة الجو لذلك يُخزن تحت ضغط في خزانات كروية أو أسطوانية الشكل. إذا تعرضت خزانات غاز البترول المسال لحريق شديد ولفترة زمنية فقد تتعرض لانفجار بخار سائل متمدد مغلي (BLEVE). يُعد انفجار البخار السائل المتمدد المغلي انفجارًا عنيفًا للغاية يحدث عند تمزق وعاء يحتوي على سائل مضغوط. ينتج عن هذا الانفجار التأثيرات التالية: (1) موجة انفجارية، (2) كرة نارية، و(3) شظايا. تهدف هذه الدراسة إلى تقييم تأثيرات انفجار البخار السائل المتمدد المغلي الناتج عن خزان غاز بترول مسال كروي سعته 1000 متر مكعب. تم تقدير الموجة الانفجارية باستخدام مكافئ ثلاثي نترو التولوين (TNT)، ونموذج الحجم النوعي والإنتروبيا والإنثالبي (SVEE)، ونموذج بروغ. كما تم تقدير الإشعاع الحراري لكرة اللهب الناتجة عن انفجار البخار السائل المتمدد المغلي باستخدام نموذج المصدر النقطي. استُخدمت الحسابات الرياضية وبرنامج إكسل لتقييم آثار انفجار الغاز المتمدد المغلي (BLEVE). وقد تبيّن أن منشآت المصنع والمباني السكنية المجاورة ستتعرض لموجات الانفجار حتى مسافة 400 متر من الخزان. كما سيتعرض العمال

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والسكان القاطنون على بُعد 400 متر تقريبًا من الخزان لخطر الإشعاع الحراري إذا كانوا خارج ملاجئهم أثناء الحادث. ويصل مدى 80% من الشظايا إلى 700 متر. وتزداد آثار انفجار الغاز المتمدد المغلي مع ازدياد كمية المواد المنبعثة.

**الكلمات المفتاحية:** غاز البترول المسال، انفجار بخار سائل متمدد مغلي، موجة انفجار، كرة نارية، شظايا.

## Introduction

Liquefied petroleum gas, also called LPG, GPL, LP Gas, liquid petroleum gas or simply propane or butane, is a flammable mixture of hydrocarbon gases used as a fuel in heating appliances and vehicles. Around 60% of the gas comes from the extraction of natural gas and oil from the earth. The other 40% is produced through the refining of crude oil (PIN, 2018). In a refinery or gas plant, LPG must be stored in pressure vessels. The vessels are either cylindrical or spherical tanks. The tanks are typically made of steel or another durable material that can withstand the high pressure and low temperatures required to store LPG in its liquid form. There are several types of LPG storage tanks, each designed for specific applications and with varying capacities. Classification of LPG tanks are summarized by Lopez, A. G. (2017). A tank type will usually be selected considering the cost or the size of transportation. The spherical type is usually employed for sizes greater than 500 $m^3$. The horizontal cylindrical type is usually used for sizes smaller than 100 $m^3$. Sphere storage vessel is preferred for storage of high-pressure fluids. The sphere is a very strong structure. The even distribution of stresses on the sphere's surfaces, both internally and externally, generally means that there are no weak points. Spheres however, are much costlier to manufacture than cylindrical or rectangular vessels. An advantage of spherical storage vessels is that they have a smaller surface area per unit volume than any other shape of vessel. This means, that the quantity of heat transferred from warmer surroundings to the liquid in the sphere, will be less than that for cylindrical or rectangular storage vessels (Abhishek, S. et al 2014). A BLEVE occurs when a pressure vessel containing a flammable liquid is exposed to fire so that the metal loses strength and ruptures. The BLEVE gives rise to the following effects: (1) blast wave, (2) fireball, and (3) fragments. The BLEVE is one of the

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most devastating types of explosions, which can result in multiple loss of life and major asset damage (Joseph, R., et al, 2021). The world has witnessed many incidents due to the operation and storage of LPG. The objective of this study is to assess the consequences of the BLEVE incident from the 1000 $m^3$ LPG spherical tank. TNT, SVEE and Prugh models have been used for the estimation of the BLEVE impacts. This study can provide references and suggestions for the layout planning of the similar tank area.

## Hazards from LPG

LPG is an important material that is indispensable in homes and businesses. But it carries significant risk because a gas leak could cause fire or an explosion. Since LPG is easily compressed at low pressure, it is mainly stored in a liquefied state in a tank and then vaporized before use. One $m^3$ of liquid LPG will vaporize into 245 to 275 $m^3$ of vapor. The heating value of LPG is 2.5 to 3 times higher than natural gas. Therefore, there is a relatively large amount of potential energy contained in a very small volume of LPG.
The accident result from the LPG tank leak could lead to the heavy casualties and serious economic losses. The event sequence after LPG leak can be shown in Figure 1.

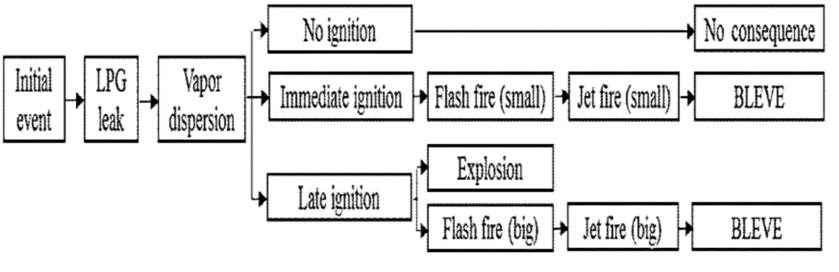


Fig. 1. Event sequences of LPG leak (Xinsheng et al., 2018).

After the LPG tank leak, the vapor cloud encounters the ignition and the flash fire will first occur. Then the flash fire will travel back to the leak hole leads to a jet fire. The high temperature of the jet fire heats the pressured vessel and result in BLEVE. Besides, the Vapor Cloud Explosion (VCE) will happen if the fire propagation velocity increase because the late ignition of vapor cloud. The accident consequence is different according to the different ignition time and

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the leak hole. For the small leak, no matter the immediate or the late ignition, the consequence that could affect the farthest distance is BLEVE. For the large leak hole or the rupture, flash fire or the VCE result from late ignition could affect the farthest distance.

## BLEVE

The Centre for Chemical Process Safety (CCPS, 2011) has defined BLEVE as 'a sudden release of a large mass of pressurized superheated liquid to the atmosphere'. The sudden release can occur due to containment failure caused by fire engulfment, a missile hit, corrosion, manufacturing defects, internal overheating, etc. Birk (1993) and Shaluf (2007) highlighted that BLEVE can be divided into three classes: BLEVE, hot BLEVE and cold BLEVE, depending on the type of event / mechanism.

BLEVE generally occurs when a pressure vessel containing a flammable liquid is exposed to fire so that the metal loses strength and ruptures (Lees F. P., 1996). Any process containing quantities of liquefied gases, volatile superheated liquid or high pressure and high temperature gases is also considered to be a good candidate for a BLEVE. The mechanism of a BLEVE can be explained in several stages. Figure 2 shows the mechanism of BLEVE development stages (Hussain, N., 2023 and Sonkar, R., 2020).

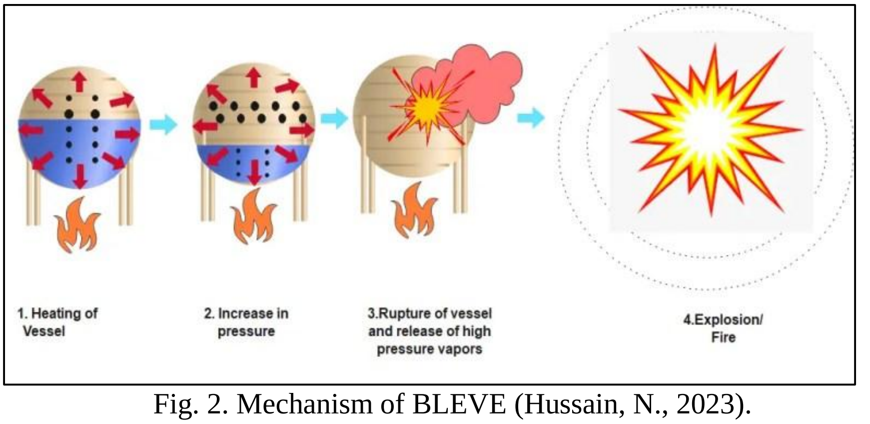


Fig. 2. Mechanism of BLEVE (Hussain, N., 2023).

## BLEVE Incidents

Several notable disasters have occurred involving BLEVEs. Feyzin and Mexico City were the worst BLEVE incidents. LPG explosion at Feyzin, France**, t**he facility was LPG tank farm with eight spheres

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containing butane and propane. A leak in a propane storage sphere occurred on 4 January 1966 at Feyzin, France. One of the worst incidents involving LPG, killing 18 people and about 80 injured. Altogether five spheres and two other pressure vessels burst and three more were damaged (Tauseef et al., 2010).

The "PEMEX LPG terminal in San Juan Ixhuatepec, Mexico City, was a large installation which received supplies from three gas refineries every day. On the morning of 19 November 1984, Four LPG spheres, each containing $1500m^3$ of LPG, and several other smaller cylinders holding between $45m^3$ and $270m^3$ of the liquid suffered BLEVEs. The PEMEX terminal was devastated. The accident was responsible for 650 deaths and over 6400 injuries. Damages due to the explosion and the resulting fire were estimated at approximately $31 million" at the 1984 currency value. Another LPG accident happened in Shandong, China. July 16, 2015, an LPG spherical tank of a chemical engineering company was leaking. BLEVE and VCE resulted in from the accident. Buildings and walls collapsed in the explosion and the fire engulfed 9 spherical tanks. All the residents within the 5 km range were evacuated (Xinsheng, H. et al., 2018). Table 1 summarizes the initiating events that trigger BLEVE (Abbasi, T et al., 2007).

**Table 1: The initiating events that trigger BLEVE (Abbasi, T. et al., 2007).**

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

## BLEVE models

In order to estimate the consequences of the BLEVE, models of the blast wave, thermal radiation and fragments (missiles) impact should be drawn.

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## 1 – Blast wave models

Blast effects which resulted in from BLEVE incident can be determined by TNT equivalency, SVEE and Prugh models. The Models have been explained by Prugh, R. W. (1991). Figure 3 shows the BLEVE explosion models.

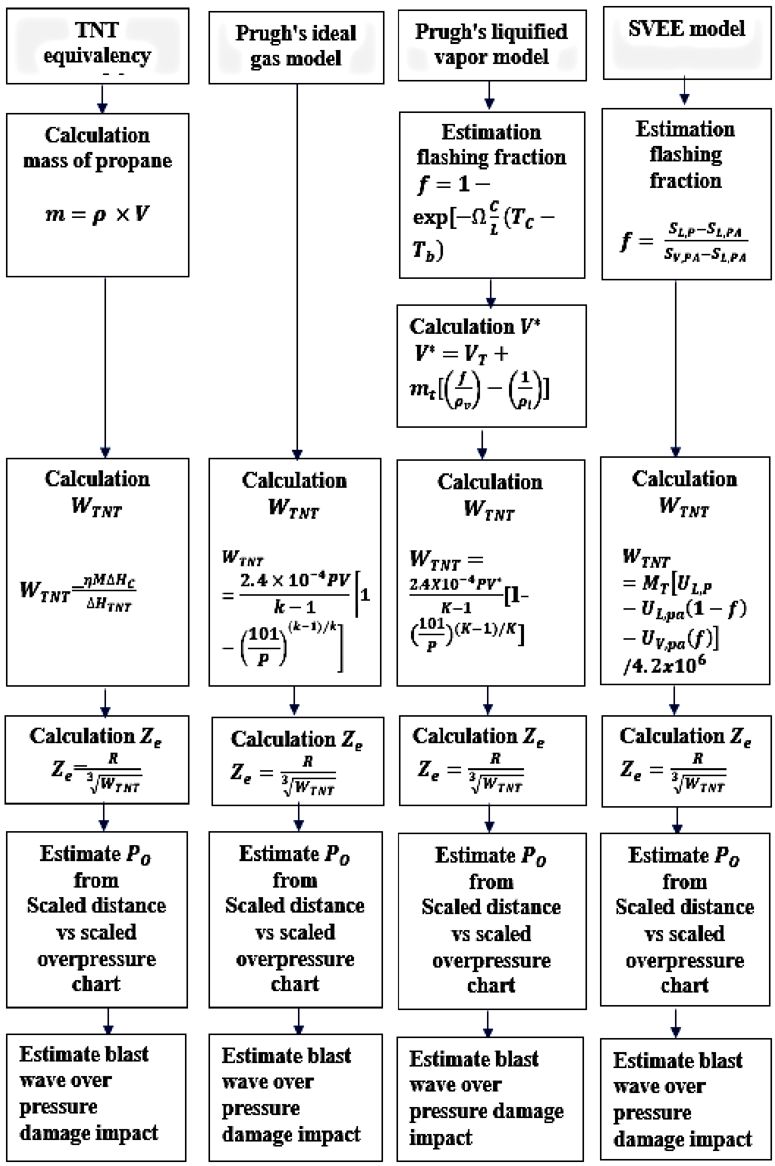


Fig. 3. BLEVE blast wave models

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When the scaled distance is calculated the side-on peak over pressure $P_O$ can be found from the scaled distance versus side on peak over pressure scaled distance. Figure 4 provides correlation between scaled distance $Z_e$ versus side-on peak over pressure $P_O$. Note: The equation symbols and their names are listed in the table of abbreviations.

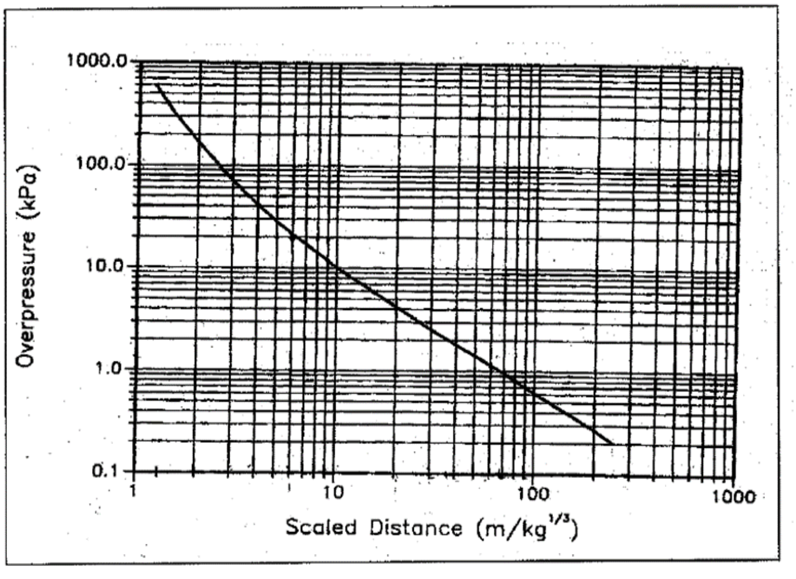


Fig. 4. Correlation between scaled distance and explosion scaled over pressure (Abdul, M., 2005)

## Over pressure damage criteria

Once the blast wave side-on peak over pressure is found the blast wave impacts can be found from the over pressure damage criteria. Table 2 summarizes the over pressure damage impacts.

**Table 2: Damage estimates based on over-pressure (Crowl, D. A. et al., 2002)**

| Psig | kPa | Damage |
|---|---|---|
| **0.02** | **0.14** | **Annoying noise (137 dB if of low frequency, 10 – 15 Hz)** |
| **0.03** | **0.21** | **Occasional breaking of large glass windows already under strain** |
| **0.04** | **0.28** | **Loud noise (143 DB), sonic boom, glass failure** |

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| Psig | kPa | Damage |
|---|---|---|
| **0.1** | **0.69** | **Breakage of small windows under strain** |
| **0.15** | **1.03** | **Typical pressure for glass breakage** |
| **0.3** | **2.07** | **"safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% window glass broken** |
| **0.4** | **2.76** | **Limited minor structural damage** |
| **0.5 – 1** | **3.4 – 6.9** | **Large and small windows usually shatter; occasional damage to window frames** |
| **0.7** | **4.8** | **Minor damage to house structures** |
| **1.0** | **6.9** | **Partial demolition of houses** |
| **1-2** | **6.9-13.8** | **Corrugated asbestoses shatters, corrugated steel or aluminum panels, fasting fail, followed by buckling;** |
| **1.3** | **9.0** | **Steel frame of clad building slightly distorted** |
| **2** | **13.8** | **Partial collapse of walls and roofs of houses** |
| **2-3** | **13.8 – 20.7** | **Concrete or cinder block walls, not reinforced, shatter** |
| **2.3** | **15.8** | **Lower limit of serious structural damage** |
| **2.5** | **17.2** | **50% destruction of brickwork of houses** |
| **3** | **20.7** | **Heavy machines (3000 lb) in industrial buildings suffer little damage** |
| **3-4** | **20.7- 27.6** | **Frameless, self-framing steel panel buildings demolished; rupture of oil storage tanks** |
| **4** | **27.6** | **Cladding of light industrial buildings ruptures** |
| **5** | **34.5** | **Wooden utility poles snap; tall hydraulic presses (40,000 lb) in buildings slightly damaged** |
| **5-7** | **34.5 – 48.2** | **Nearly complete destruction of houses** |
| **7** | **48.2** | **Loaded train wagons overturned** |
| **7-8** | **48.2-55.1** | **Brick panels, 8-12 in thick, not reinforced, fail by shearing or flexure** |
| **9** | **62.0** | **Loaded train boxcars completely demolished** |
| **10** | **68.9** | **Probable total destruction of buildings; heavy machine tools (12,000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survive** |
| **300** | **2068** | **Limit of crater lip** |

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## 2 – Thermal radiation models

Prugh (1991) summarized the relationships selected by the Centre for Chemical Process Safety for fire ball thermal radiation models as follows:

Fireball diameter $D = 6.48\ m^{0.325}$ meters (1)

Fireball duration $t = 0.825\ m^{0.26}$ seconds (2)

Fireball elevation $H = 0.75\ D$ meters (3)

View factors $F_{21} = \frac{D^2}{4X^2}$ (4)

Atmospheric transmissivity $\tau = 2.02(P_w X)^{-0.09}$ (5)

Surface power density $E = \frac{F_{rad}\ m\ H_c}{\pi(D)^2 t}$ kW/m$^2$ (6)

Received power flux $Q_R = E\ \tau\ F_{21}$ kW/m$^2$ (7)

### Thermal Radiation Criteria:

Thermal radiation from fires and explosions causes a wide range of damage on people and structures. Table 3 summarizes thermal radiation criteria for personnel and Table 4 summarizes thermal Radiation Impacts criteria for Equipment. Table 3: Thermal radiation impact criteria for personnel (IOCL, 2018), (Khayyam, O., 2005).

**Table 3: Thermal radiation criteria (Khayyam, O., 2005)**

| Radiation Intensity ($kW/m^2$) | Impact |
|---|---|
| 1.2 | received from sun in summer at noon |
| 1.6 | Minimum necessary to be felt as pain |
| 4.7 | Pain in 15-20 seconds, 2nd degree burns after 30 s. |
| 12.6 | 30% chance of fatality for continuous exposure. |
| 23.0 | 100% chance of fatality for continuous exposure. 10% chance for instantaneous exposure. |
| 35.0 | 25% chance of fatality for instantaneous exposure. Damage to process equipment. |
| 60.0 | ~100% chance of fatality for instantaneous exposure |

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**Table 4: Thermal Radiation Impacts criteria for Equipment (IOCL, 2018)**

| Thermal Radiation ($kW/m^2$) | Effect Description |
|---|---|
| 4 | Glass breakage (30-minute exposure) |
| 12.5 - 15 | Piloted ignition of wood, melting of plastic (>30-minute exposure) |
| 18 - 20 | Cable insulation degrades (>30-minute exposure) |
| 10 - 20 | Ignition of fuel oil (120 or 140 seconds, respectively) |
| 25 - 32 | Unpiloted ignition of wood, steel deformation (>30-minute exposure) |
| 35 - 37.5 | Process equipment and structural damage (including storage tanks) (>30-minute exposure) |
| 100 | Steel structure collapse (>30-minute exposure) |

## 3 – Fragments Models

BLEVE events often generate large vessel fragments that may be propelled long distances. In fact, in many cases, the longest reaching hazard associated with BLEVE events is projectiles or rocket-type fragments. The fragments associated with BLEVE generally not evenly distributed. Therefore, fragments can be launched in any direction (Abdul, M. I., 2005). According to Birk (1995), as a crude approximation, projectile ranges can be related to the fireball radius. 80 to 90% of rocketing fragments fall within 4 times the fireball radius.

## Case study

A refinery has six LPG spherical tanks. The LPG spherical tanks named LPG - 1 to LPG - 6 are used to store the LPG products. Four small LPG spherical tanks LPG – 1, 2, 3, and 4. Each small tank has capacity 500 cubic meters. Two large spherical tanks LPG – 5 and 6, each of which has capacity 1000 cubic meter. The layout of the LPG spherical tanks and the separation distance between the tanks are shown in Figure 5.

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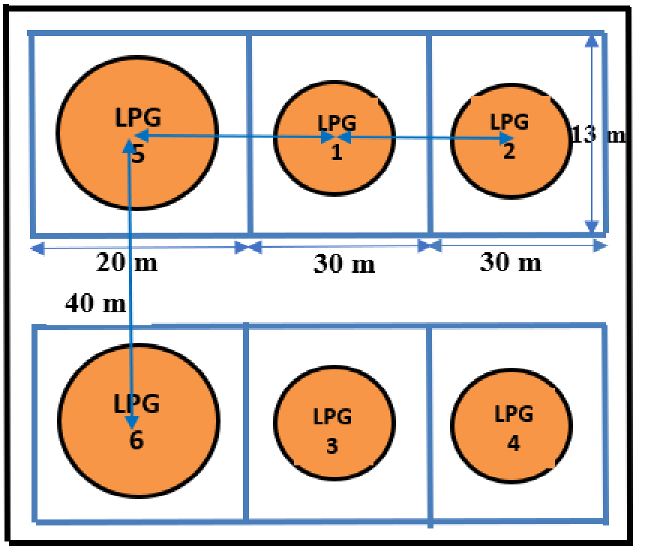


Fig. 5. The lay out of the LPG spherical tanks

The LPG spherical tanks are provided with the inlet, suction, transfer, return, balance, drain and discharge lines. The inlet line is to feed the tank with the LPG products. The suction line is to carry out two operations simultaneously. The transfer line is used to transfer the LPG material from spherical tank to another spherical tank during maintenance and in case of emergency. The return lines are used to return the product in case of the LPG products does not meet the specification. The balance line transfers the product to the empty tanks in case of the tank is over filled. The circulation line is to circulate the product from bottom and returned back in the top of the tank until the products become homogenous. The circulation process usually takes about 4 hrs. Then a sample of LPG is taken to the laboratory to make sure the LPG meets the required specification in order to issue a certificate that the gas is suitable for cooking uses. The LPG spherical tanks are provided with control and protective systems as well as firefighting system. Figure 6 shows the LPG spherical tank. Four gas detectors are placed on the ground at the angles of the dike to detect any gas leak.

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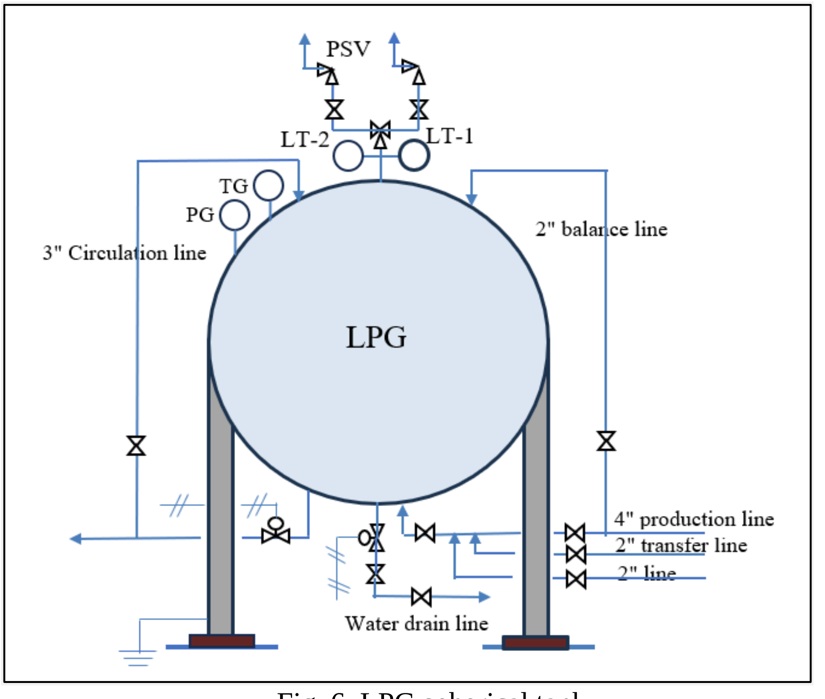

Fig. 6. LPG spherical tank

The Characteristics of LPG spherical tank has been summarized in Table 5.

**Table 5: 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 |

## Estimation blast wave from LPG – 6

1 - Mathematical calculations

The estimation of blast wave from LPG – 6 was carried out by mathematical calculation by the TNT Equivalency model, Prugh's

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Model, SVEE model at 85% of tank capacity. Table 6 summarizes the models mathematical calculations findings.

**Table 6: BLEVE blast wave models findings**

| | TNT Equivalency model | Prugh's Model | | SVEE model |
|---|---|---|---|---|
| | | Ideal gas | Liquified vapor | |
| $W_{TNT}$ | 456685 | 416 | 2357 | 3978 |
| R(m) | 100 | 100 | 100 | 100 |
| $Z_e\ (m/kg^{1/3})$ | 1.29 | 13.3 | 7.51 | 6.31 |
| $P_0\ (kPa)$ | 800 | 9 | 10.6 | 20 |
| Impacts | Probable total destruction of buildings; heavy machine badly damaged | Steel frame of clad building slightly distorted | Steel frame of clad building slightly distorted | Heavy machines in industrial buildings suffer little damage; steel frame buildings distort |

## 2 - EXCEL Calculations

EXCEL program has been used for the estimation of the blast wave consequences at selected degree of fill of the LPG tank. Table 7 summarizes the $W_{TNT}$ at 10%, 25% and 50% degree of fills of the LPG tank at 400 m.

**Table 7: $W_{TNT}$ at 10%, 25% and 50% degree of fills of the LPG tank.**

| Degree of fill (%) | Mass (kg) | $W_{TNT}$ TNT Equivalency Model | $W_{TNT}$ Prugh's model | | $W_{TNT}$ SVEE model |
|---|---|---|---|---|---|
| | | | Ideal gas | Liquefied vapor | |
| 10 | 49900 | 53727.7383 | 41.6214 | 274.011 | 467.125 |
| 25 | 124750 | 134319.345 | 104.053 | 685.029 | 1167.814 |
| 50 | 249500 | 268638.691 | 208.107 | 1370.058 | 2335.629 |

The scaled distance, side on peak over pressure, and the impacts have been found for the models and summarized in Table 8.

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**Table 8: The scaled distance, side on peak over pressure, and the impacts by the models**

| Models | | | LPG tank degree of fill | | |
|---|---|---|---|---|---|
| | | | 10% | 25% | 50% |
| TNT Equivalency | | $Z_e$ | 10.354 | 7.629 | 6.055 |
| | | $P_O$ | 8 | 15 | 20 |
| | | Impact | Corrugated steel or aluminum panels, fasting fail, followed by buckling | Concrete or cinder block walls, not reinforced, shatter | Concrete or cinder block walls, not reinforced, shatter |
| | | | | | |
| Prugh | Ideal gas | $Z_e$ | 112.735 | 83.664 | 65.928 |
| | | $P_O$ | 0.6 | 0.8 | 1 |
| | | Impact | Loud noise. Breakage of small windows under strain | Typical pressure for glass breakage | Typical pressure for glass breakage |
| | Liquified vapor | $Z_e$ | 60.151 | 44.319 | 35.176 |
| | | $P_O$ | 1.2 | 1.8 | 2.1 |
| | | Impact | Limited minor structural damage | Typical pressure for glass breakage | Typical pressure for glass breakage |
| | | | | | |
| SVEE | | $Z_e$ | 50.355 | 37.1 | 29.446 |
| | | $P_O$ | 1.5 | 2 | 2.8 |
| | | Impact | Typical pressure for glass breakage | Some damage to house ceilings; 10% window glass broken | Limited minor structural damage |

The BLEVE side-on peak over pressure which resulted in from LPG - 6 was estimated at 10%, 25%, and 50% of the capacity of the LPG spherical tank. It has been noted that the peak overpressure as well as the consequences of the blast wave increase with the increasing the capacity of the LPG tank. The extent of the damage ranges from the light rupture of industrial building to total destruction.

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## Fireball thermal radiation

EXCEL program has been used for the estimation of the BLEVE fireball thermal radiation from LPG – 6 at certain degree of fill percentage. Table 9 summarizes the BLEVE fireball thermal radiation which results in from the tank at several degree of fill percentage.

**Table 9: BLEVE fireball thermal radiation at different degree of fill percentage**

| Degree of fill % | Thermal radiation ($kW/m^2$) | | | | | |
|---|---|---|---|---|---|---|
| | Mass (kg) | 100 (m) | 200 (m) | 300 (m) | 400 (m) | 500 (m) |
| 1 | 4990 | 29.21 | 10.15 | 4.86 | 2.81 | 1.82 |
| 10 | 49900 | 67.29 | 37.04 | 21.17 | 13.23 | 8.93 |
| 20 | 99800 | 78.24 | 49.59 | 30.80 | 20.12 | 13.92 |
| 30 | 149700 | 84.11 | 57.43 | 37.57 | 25.31 | 17.83 |
| 40 | 199600 | 88.02 | 63.06 | 42.83 | 29.55 | 21.13 |
| 50 | 249500 | 90.91 | 67.42 | 47.12 | 33.15 | 24 |

As per the criteria of the thermal radiation impacts in Tables 3 and 4, it has been noted that the thermal radiation levels which could have been resulted from BLEVE fireball at several percentage of tank fill degree have severe impacts on workers as well as on the residents who live up to 500m from the LPG tank.

## Estimation of fragments range from LPG - 6

EXCEL program has been used for the estimation of the fragments range from BLEVE in LPG – 6. Table 10 summarizes the fireball diameter and the fragments range.

**Table 10: Fireball diameter and Fragments range from LPG – 6**

| Fill rate % | Fireball diameter (m) | Fragments range (m) |
|---|---|---|
| 1 | 103.147 | 206.294 |
| 10 | 218.001 | 436.001 |
| 20 | 273.081 | 546.163 |
| 30 | 311.545 | 623.091 |
| 40 | 342.079 | 684.159 |
| 50 | 367.809 | 735.619 |

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The fragments effects range has been based on the 80 to 90% of rocketing fragments fall within 4 times the fireball radius. Fragments from LPG spherical tank are not distributed evenly, often projecting with high kinetic energy and velocity, creating significant domino effects. It has been noted that the fireball diameter increases with increasing of the capacity of the tank and consequently the range of the fragments increases with the capacity of the tank.

**Discussion of results**

In this work it was highlighted that the BLEVE incident results in three major effects, blast wave, fireball and fragments. The blast wave is one of the hazardous effects. The important parameter that needs to be taken into consideration is the over pressure. The blast wave over pressure has been estimated at 100m from the tank when the tank capacity is 85%. The value obtained by TNT equivalency method is higher than those obtained by Prugh and SVEE. The TNT equivalent model often produces higher results than the SVEE because it assumes a more rapid, concentrated energy release. TNT model often overpredict near-field, short-duration blast waves. SVEE models are more accurate for fuel-air mixtures, which have slower burn rates and lower shock pressure. The damage produced by over pressure is summarized in Table 5. It is probable that total destruction of buildings which are in the vicinity of the tank. Some of the community residential houses are located at about 400m from the LPG tank. The over pressure estimation has been carried out at 10%, 25% and 50% of the tank capacity. It has been noted that the concrete walls which are not reinforced shatter. The damage produced by over pressure is summarized in Table 7.

The BLEVE fireball thermal radiation effects have been estimated based on point source model at different capacities of the tank at 100m, 200m, 300m, 400m and 500m. it has been noted that the thermal radiation has severe impacts on the workers and residents who are not protected by shelter during the incident. The thermal radiation values have been summarized in Table 8.

The third effect is the fragments (missiles). The range of the effect of the fragments has been estimated based on the 4 times the fireball radius. 80% of fragments range reaches up to 700m. The probability of fragments hit the workers as well the community residents who are near the spherical tank and not protected by shelters increases

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by the increasing capacity of the tanks. The fragments range is summarized in Table 9.

## Conclusions

The BLEVE is one of the most devastating types of explosions in chemical process industry. The BLEVE side-on peak over pressure which resulted in from LPG - 6 was estimated at 10%, 25%, and 50% of the capacity of the LPG spherical tank. It has been noted that the peak overpressure as well as the consequences of the blast wave increase with the increasing the capacity of the LPG tank. The extent of the damage ranges from the light rupture of industrial building to total destruction**.** It has been noted that BLEVE fireball thermal radiation has severe impacts on workers as well as on the residents who live up to 500m from the LPG tank. It has been noted that 80% of fragments range reaches up to 700m. The probability of fragments hit the workers as well the community residents who are near the spherical tank and not protected by shelters increases by the increasing capacity of the tanks.

It is recommended for high-risk industries to keep the inventories of hazardous material as low as possible to limit the risk inside their perimeter. It is also advisable that the management of MHIs to share the offsite emergency response plan with the responsible authority. The responsible authority should not allow the community to live near the borders of the MHIs. Architectural and civil engineers who are involved in the early design of the buildings of the process industry should be familiar with process hazards to choose the location, material and direction of buildings (control room and offices) to reduce the impacts of explosion.

**Table 11. Table of Abbreviations**

| Symbol | Name | Symbol | Name |
|---|---|---|---|
| $C$ | **Average specific heat of liquid ( J/kg-K)** | $T_C$ | **The critical temperature (°C)** |
| $D$ | **Fireball diameter (m)** | $T_O$ | **The initial temperature (°C)** |
| $E$ | **Fireball surface power density (kW/m$^2$)** | $U_{L,P}$ | **Internal energy of liquid ($kJ/kg$)** |
| $f$ | **Flashing fraction** | $U_{L,Pa}$ | **Internal energy of liquid at** |

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| Symbol | Name | Symbol | Name |
|---|---|---|---|
| | | | atmospheric pressure $(kJ/kg)$ |
| $F_{21}$ | view factor (dimensionless), | $U_{V,Pa}$ | Internal energy of vapor at atmospheric pressure $(kJ/kg)$ |
| $H$ | Fireball elevation $(m)$ | $V$ | Volume $(m^3)$ |
| $k$ | The specific heat ratio | $V^*$ | Volume of vapor in vessel and the volume the liquid flashed to vapor. |
| $L$ | Latent heat of vaporization $(J/kg)$ | $V_T$ | The total volume of the container $(m^3)$ |
| $m$ | Mass of propane $(kg)$ | $X$ | The distance from the point source to the receptor $(m)$ |
| $m_T$ | The mass of liquid in the container $(kg)$ | $W_{TNT}$ | The mass of TNT $(kg)$ |
| $P$ | Pressure ( $kPa$, absolute) | $Z_e$ | Scaled distance $(m/kg^{1/3})$ |
| $Q_R$ | Received power flux $(kW/m^2)$ | $\Delta H_C$ | The heat of combustion of flammable gas $(kJ/kg)$ |
| $R$ | The distance from blast $(m)$ | $\Delta H_{TNT}$ | The heat of combustion of TNT $(kJ/kg)$ |
| $P_O$ | Over pressure $(kPa)$ | $\tau$ | The atmospheric transmissivity |
| $P_W$ | Water partial pressure $(N/m^2)$ | $\rho$ | Density $(kg/m^3)$ |
| $S_{L,P}$ | Entropy for liquid | $\rho_L$ | The density of the liquid $(kg/m^3)$ |
| $S_{L,PA}$ | Entropy for liquid at atmospheric pressure | $\rho_V$ | The density of the gas $(kg/m^3)$ |
| $S_{V,Pa}$ | Entropy for vapor at atmospheric pressure | $\eta$ | The explosion efficiency |
| $t$ | Fireball duration $(s)$ | | |
| $T_b$ | The boiling point (°C) | | |

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## References

Abbasi, T., Abbasi, S. A. (2007) "The boiling liquid expanding vapor explosion (BLEVE): Mechanism, consequence assessment, management" Journal of Hazardous Materials 141(3):489-519.

Abdul, M. I. B. (2005) " Development of Boiling Liquid Expanding Vapor Explosion (BLEVE) Model for Process Plant Design" dissertation, Universiti Teknologi PETRONAS.

Abhishek S., N. K. Jain, Praveen Patel (2014) "Analysis of BLEVE Mechanism and Anti BLEVE System in Pressurized Tank" International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 1.

Birk, A. M., Ye, Z, Maillette, J. and Cunningham (1993) "Hot and Cold BLEVEs: Observation and Discussion of Two Different Kinds of BLEVEs" AICHE Symposium, Vol. 89, pp 119 – 130.

Birk. A.M. (1995) "Scale effects with fire exposure of pressure-liquefied gas tanks" Journal of Loss Prevention in the Process Industries. Volume 8, issue 5, pages 275 290.

CCPS. (2011). Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs 2nd ed. New York: American Institute of Chemical Engineers.

Crowl, D. A., Louvar, J. f. (2002) "Chemical process Safety Fundamentals with Applications" Second Edition, Prentice Hall International Series.

Hussain, N. (2023) "Boiling Liquid Expanding Vapor Explosion" https://thepetrosolutions.com/boiling-liquid-expanding-vapour-explosion/ accessed on (April 2025).

Josef, R., Karthikeyan, N. T., Velmurugan, V. G. (2021) "Safety Integrity Level Assessment for LPG Storage System" IJESC, Volume 11 issue No. 06.

Khayyam, O. (2005) "Vulnerability Models" Chapter 7, https://www.uobabylon.edu.iq/eprints/publication_7_13119_6247.pdf. https://www.globalspec.com/reference/24872/203279/chapter-7-vulnerability-models. Accessed on (May 2025).

INDIAN OIL CORPORATION LIMITED (IOCL, 2018) "Quantitative Risk Assessment of LPG Bottling Plant, Raipur" Report No – Polite/IND/2017/IOCL – Raipur.

http://www.doi.org/10.62341/fsml7468

Lees, F. P. (1996). (2nd Edition). Loss Prevention in the Process Industries: Hazards Identification, Assessment and Control, Volume 1 and 2. Oxford: Butterworth-Heinemann, Reed Education and Professional Publishing Ltd.

Lopez, A. G. (2017) " Risk analysis of LPG tanks at the wildland-urban interface" Master en Ingenieria Quimica, Universittat Politechnica De Catalunya.

PIN (2018) " How is LPG Produced?" https://www.petro-online.com/news/analytical-instrumentation/11/breaking-news/how-is-lpg-produced/47566 accessed on (December 2025).

Prugh, R. W. (1991) "Quantitative Evaluation of "BLEVE" Hazards" Journal of fire protection 3(1) pp 9–24.

Shaluf, I. (2007) "An overview on BLEVE" Disaster Prevention and Management. An International Journal 16(5):740-754

Sonkar, R. (2020) "Understanding & Managing Boiling Liquid Expanding Vapor Explosion" https://www.isrmag.com/understanding-managing-boiling-liquid-expanding-vapour-explosion/ accessed on (February 2025).

Tauseef, S. M., Abbasi, T., Abbasi, S. A. (2010). "Risks of Fire and Explosion Associated With the Increasing Use of Liquefied Petroleum Gas" Journal of Failure Analysis and Prevention 10(4):322-333.

Xinsheng, H., Zongzhi, W., Lifang, X., Rujun, W. (2018) "Quantitative Risk Assessment of LPG Tank Area" 7th International Conference on Energy, Environment and Sustainable Development (ICEESD 2018), Volume 163.