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# Analysis of BLEVE Mechanism and Anti BLEVE System in Pressurized Tank

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## Abstract

*LPG (Liquefied Petroleum gas) by nature is highly flammable and explosive which can cause numerous emergency hazards if not stored under pressure with proper Safety Standards with safe construction. This Paper mainly focus on the various aspects of pressurized storage tank and BLEVE is most common hazard associated with pressurised tanks, it also focus on the mechanism and anti BLEVE Safety system. To avoid fire emergency in storage tank. By taking butane and propane into consideration basic calculation are performed like Vessel Pressure Stress Analysis, Vessel Pressure versus Ambient Temperature, Radiant Heat Transfer Calculation ,Temperature Rise In System, Rate of Vessel Emptying.*

## 1. Introduction

LPG (Liquefied Petroleum Gas) is mixture of different hydrocarbons (mainly Propane, I-Butane and n-Butane).LPG if compressed or refrigerated can be stored as liquid or at ambient temperatures it can be stored in containers as a liquid under pressure thus possess various hazards.LPG also cause numerous emergency hazards if not stored properly. The Properties of gases composing LPG are as follows:-

| **GAS** | **PROPANE** |
|---|---|
| Chemical formula | $C_3 H_8$ |
| Molecular weight | 44 |
| Specific weight | 0.510 Kg/l |
| Boiling point | -43°C |
| Low heat value | 11070 Kcal/Kg |
| Fire point °C | 510°C in air |
| Explosive limit | 2.1 - 9.5 |
| **GAS** | **BUTANE** |
| Chemical formula | $C_4 H_{10}$ |
| Molecular weight | 58 |
| Specific weight | 0.580 Kg/l |
| Boiling point | -1.1°C |
| Low heat value | 10920 Kcal/Kg |
| Fire point °C | 490°C in air |
| Explosive limit | 1.5 - 8.5 |



## 2. General

### 2.1 Pressurized Storage Tanks

Standard tanks are not suitable for the storage of liquefied petroleum gases, such as propane or butane, owing to the high pressure required to maintain these gases in a liquid state; they are therefore stored in special pressure vessels. The ideal shape for a pressure vessel is spherical, as the internal pressure is the same at any point, but long, heavily-built small diameter horizontal tanks with rounded ends are also used.

### 2.2 Spheres

This type of storage vessel is preferred for storage of high pressure fluids. A 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 more costly to manufacture than cylindrical or rectangular vessels. Storage Spheres need ancillary equipment similar to tank storage - e.g. Access manholes, Safety valves, Access ladders, earthing points etc.

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.

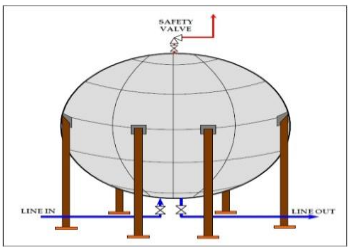


**Figure-1- SPHERE TANK**

### 2.3 Horizontal Pressure Vessels

Horizontal pressure vessels for the storage of volatile oils or gases under pressure having pressure range from 100 to 220 psi and are easily recognizable by their rounded ends. They are more stoutly constructed than normal vertical cylindrical tanks and, of course, incorporate suitable pressure relieving devices. Fire walls (or bunds) may be provided, but in newer installations similar arrangements exist for collecting spilled liquid and directing it into safer areas. There is also water draw-off piping at the base of the tanks similar to that on spheres.

### 2.4 Refrigerated Tanks

There is an economic advantage in refrigerated storage over pressure storage for very large quantities of liquid, and owing to the increase in the quantities of L.P.G. which are being used in recent years, giant refrigerated tanks pf 100 ft (30m) in height may now be found at oil refineries. At atmospheric pressure, propane boils at -42 C and normal butane at 0.6 C. By cooling to below boiling and maintaining the liquids in a chilled state, it is possible to store them in tanks designed to operate at slightly above atmospheric pressure. Cryogenic storage spheres are also used for the storage of liquefied ethylene gas at a temperature of 104 C enabling it to be stored at atmospheric pressure instead of under pressure as normally necessary.

### 2.5 Fully Refrigerated Storage

Tanks are either of single or double wall construction, the inner tank is enclosed by an outer tank constructed from low carbon steel and the annular space between the tanks is filled with an insulating material e.g. perlite. As a safety measure the annular space may contain an inert gas, such as nitrogen.

### 2.6 Refrigerated Pressure Storage

Refrigerated pressure storage (sometimes called semi-refrigerated storage) combines partial refrigeration with low or medium pressure. These storage tanks are usually spherical in shape and can be 40ft (12m) or more in diameter.

## 3. BLEVE

The term "BLEVE"**(**Boiling Liquid Expanding vapour cloud Explosion) was first introduced by J. B. Smith, W. S. Marsh, and W. L. Walls of Factory Mutual Research Corporation in 1957.Walls (1979). BLEVE occurs when there is a sudden loss of containment of a pressure vessel containing a superheated liquid or liquefied gas. The primary cause is usually an external flame impinging on the shell of a vessel above the liquid level, weakening the container and leading to sudden shell rupture.

### 3.1 BLEVE Mechanism

The mechanism of BLEVE may vary for the different conditions to which a tank is subjected. The results of BLEVE are same in all subjected condition.
The different conditions which may cause the BLEVE are

1. The tank receives the heat load – this may be due to missile hit, fatigue or corrosion of material of tank.

2. The vessel fails – the vessel may get fail due to malfunction of the preset relief valves.

3. Instantaneous depressurization and explosion

4. The tank is shatter – the storage tank may violently break into small pieces resulting in the splashing of liquid and forming small pool before vaporizing and toxic release.



### 3.2 BLEVE calculations

#### 3.2.1 Blast Effects

Blast effects in BLEVE can be determined by TNT equivalent. The TNT equivalent model is based on the assumption between flammable material and TNT factored by a term

$$W = \frac{\eta M E_c}{E_{TNT}}$$

Where,
W is the mass of TNT (Kg)
η is the equivalent explosion efficiency
M is the mass of hydrocarbon (kg)
$E_c$ is the heat of combustion of flammable gas (kJ/kg)
$E_{TNT}$ is the heat of combustion of TNT (4437-4765 kJ/kg)

#### 3.2.2 Fragments

Fragments are usually not evenly distributed. The vessel's axial direction receives more fragments than the side directions. The total no. of fragments is approximately a function of vessel size

No. of fragments = -3.77 + 0.0096 [Vessel capacity ($m^3$)]

### 3.2.3 Thermal Radiation

Thermal radiation is usually calculated using surface emitted flux, E. Surface heat flux based on the radioactive fraction of the total heat of combustion.

$$E = \frac{RMH}{\pi D^2_{max} * t_{BLEVE}}$$

Where

E is the radiative remissive flux (energy/area time)

R is the radiative fraction of the heat of combustion

M is the mass of fuel in the fireball (mass)

H is the net heat of combustion per unit mass (energy/kg)

$D_{max}$ is the maximum diameter of the fireball (length)

$t_{BLEVE}$ is the duration of the fireball (time)

Product Description

The product stored in the storage tank is butane. The formula of Butane is $C_4H_{10}$.

Thermodynamic Properties of butane are

- Boiling Point is = – 1.1 °C at $P_{atm}$.
- Molecular Weight (M) = 58
- Gas Constant(R ) = 143 J/kg°C
- Calorific Value = 49 MJ/kg
- Flammability Limits (in air)= 1.5 % to 8.5 %
- Liquid Density = 599 kg/$m^3$ (at 1bar)
- Vapour Density = 2.489 kg/$m^3$ (at 1bar)
- Specific Heat($C_p$) = 1675 J/kgK
- Ratio of Specific Heats (γ) = $C_p/C_v$ = 1.094
- Latent heat of evaporation (λ) = 386 kJ/kg

Containment Description

The vessel is large outdoor spherical vessel resting on vertical legs designed for the bulk storage of liquefied Butane. There is a pressure relief valve (safety valve) at the top on a pipeline leading to a flare. In emergencies this valve would open and the escaping vapour flared off.

Vessel geometry is as follows

- Vessel Diameter D = 14 m
- Vessel Radius, R = 7 m
- Total Volume ($V_{total}$ ) = 4/3πR$^3$ = 1437 $m^3$
- Ullage (i.e. free space) set at 20 %
- Working Volume ($V_{working}$ ) = 0.8 x 1437 = 1150 $m^3$

Vessel Geometry

Material of construction is structural steel with a density $\rho_s$ = 7800 kg/$m^3$

Wall thickness, t = 45 mm

Mass of tank wall = 4πR2 t $\rho_s$ =216 tonnes

Surface area of tank = 4πR2 = 616 $m^2$

Projected area of tank = πR2 = 154 $m^2$

Vessel Pressure Stress Analysis

Tensile Strength (maximum strength) of structural steel ($\sigma_{TS}$) = 620 MN/$m^2$

Rupture Pressure can be estimated from knowledge of the membrane stress in a spherical vessel = $P_R$ = 80 bar

$$P_R = \frac{4t\,\sigma_{TS}}{D} = \frac{4\,x\,0.045\,x\,620x10^6}{14}$$

Under normal conditions, the vessel would not be expected to rupture until the internal (Butane) pressure reached 80 bar.

If Vessel was un-insulated

Butane temperature = Ambient outside temperature.

Vessel Pressure versus Ambient Temperature

Storage pressure (i.e. Butane vapour pressure) varies with ambient (i.e. Butane) temperature.

For this location: - 20 °C < $T_{AMB}$ < 40 °C

Hence can tabulate the normal pressures that might exist within the gas storage spheres.

| $T_{AMB}$ (°C) | $P_V$ (BAR) |
|---|---|
| - 20 | 4 |
| 0 | 7 |
| 20 | 9.5 |
| 40 | 13 |

Rupture Description

For Example 400 tonnes of Butane is stored in the tank.

$$V = \frac{m}{\rho} = \frac{400x10^3}{599}$$

- Volume occupied ( V ) = 668 $m^3$
- Given the working volume ( $V_W$ )= 1150 $m^3$
- If Tank was approximately 58 % full.

Radiant Heat Transfer Calculation

- Initial temperature of Butane tank $T_i \cong 0$ °C
- How long will it take for upper tank wall to reach 700 °C?
- Do a very crude energy balance?

Radiant heat flux ($Q_R$ ) = ε.σ.A. ($T_{Flame}^4 - T_{Wall}^4$)

Taking,

- $T_{Flame}$ = 1300 °C = 1600 K
- $T_{Wall}$ = ½(0 °C + 700 °C) = 350°C = 620 K
- A is the projected area of the sphere = 154 $m^2$
- Stefan-Boltzmann Constant (σ )= 5.67 x $10^{-8}$ W/$m^2$K
- Emissivity ε (really a fudge factor), Take ε = 0.5
- $Q_R$ = 0.5 x 5.67 x $10^{-8}$ x 154 x ($1600^4 - 620^4$)
- $Q_R$ = 28 MW i.e. 28 MJ/s

Temperature Rise in System

Calculate the amount of thermal energy needed to produce the corresponding temperature rise of the system so that the upper wall reaches 700 °C. Note the total heat in has sensible heat transfer and latent heat transfer components:

$$Q = mc_p \Delta T + J\lambda$$

1. Bring 400 tonnes of butane from 0 °C up to 60 °C.
2. Bring approximately half of tank wall (108 tonnes of steel) from 0 °C up to 60 °C.
3. Bring other half of tank wall from 0 °C up to 700 °C.
4. Evaporate off some portion (say half) of the butane.

Note the specific heat capacity of steel $c_p$ = 450 J/kgK

Temperature Rise in System:

Q = 400 x $10^3$ x 1675 x (60 – 0) (1)
+ 108 x $10^3$ x 450 x (60 – 0) (2)
+ 108 x $10^3$ x 450 x (700 – 0) (3)
+ 200 x $10^3$ x 428 x $10^3$ (4)

Q = 40.2 + 2.916 + 34.02 + 85.6 GJ
= 162.73 GJ

Dividing the total heat requirement by the heat flux to obtain time

$$t = \frac{Q}{Q_R} = \frac{162.73\,x10^9}{28\,x10^6}$$

= 5811.7 sec ≈ 5812
t = 5812 sec

So, very roughly we might expect that one hour and a half after the outbreak of the initial fire, the tank wall temperature will reach 700 °C.

Rate of Vessel Emptying

How much vapour has been expelled through the safety valve after an hour and a half (and assuming the safety valve lifts soon after the fire starts)?

Require the mass flux through the safety valve; model the process as isentropic expansion of an ideal gas across a nozzle with choked flow at outlet.

$$J = \frac{PA}{\sqrt{T}}\sqrt{\frac{\gamma}{R}}\sqrt{\frac{\gamma+1}{2}}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

J Mass flow rate (kg/s)
P Vessel pressure (bar)
A Valve outflow area (m2)
T Butane vapour temperature (absolute) (K)

Rate of Vessel Emptying:
P = 20 bar,
T = 60 °C = 333 K

$$A = \frac{\pi}{4}0.1^2$$ (Valve dia. = 100 mm)

=0.008 $m^2$
γ = 1.094
R = 143 J/kgK (Butane)

Mass flow rate =

$$J = \frac{PA}{\sqrt{T}}\sqrt{\frac{\gamma}{R}}\sqrt{\frac{\gamma+1}{2}}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

= 45.94 kg/s

Total outflow of Butane in 5812 s
J = 45.94 x 5812 = 267 tonnes

Thus after an hour and a half, the amount of Butane remaining in the tank is 400 – 267 = 133 tonnes.

## 4. Anti BLEVE Safety System

The anti BLEVE safety system can be used with new and all existing large storage.

This system is a simple, low-cost, completely automatic and self-actuating device that prevents pressurized fuel tanks from exploding.

The system has a simple turbo-charger inside the tank. This uses the vapour which is escaping through the pressure safety relief valve and spins the turbo-charger. The turbo charger then takes in liquefied gas from just below the surface near the shell of the tank, and sprays it vertically upwards to cool the top part of the tank. There is also a vapor relief exit which sends out the vapors from turbo motor after rotating it.

Thus this system cools the tank from inside and prevent BLEVE occurrence.

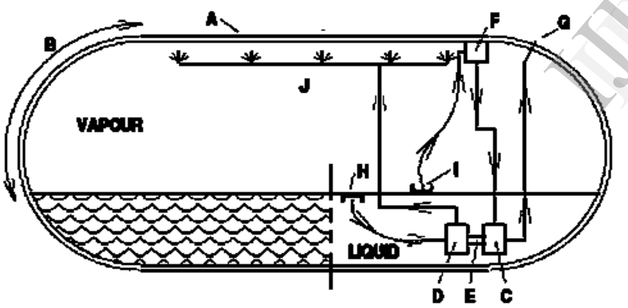


**Figure-2- Anti BLEVE System**

A- Tank
B- Heat transfer path
C- Turbo motor
D- Rotary pump
E- Connecting shaft
F- Pressure relief valve
G- Vapour relief exit
H- Self acting liquid intake
I- Self acting vapour intake
J- Liquid spray nozzles

### 4.1 BLEVE Prevention

BLEVE can be prevented by following ways:

- By preventing the exposure of tank to fire.
- By preventing mechanical damage.
- By preventing overpressure of tank.
- By preventing overfilling of tank.

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