BLEVE of a road tanker LPG - A Short Review

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ABSTRACT
The BLEVE is a kind of technological accident with a major impact on society due to the possibility of causing death and disability on people as well as property damage. This kind of accident is the result of the production of a pressure wave generated by the release of stored energy, of the heat flux generated by a fireball and the projection of fragments generated by the rupture of the shell and materials from other sources. The probability of a BLEVE happening is greater when the equipment is portable, especially if the transport is made by road. In this work is shown a brief survey of the state of the art in relation to the type of accident BLEVE (phenomenon, construction of tanks and consequences), simulation models of explosions and of the combination of the assessment of the consequences with a road tanker LPG. Finally some conclusions are drawn about the state of the art in this area.

Keywords: BLEVE, Accident, transport, tanker.

1. INTRODUCTION

LPG is a fuel gas, butane or propane, which is in a liquefied state and is used domestically for heating sanitary water, central heating and cooking. It is also used industrially in the production process for generation of energy or for water heating and thermal comfort. Currently, for energetic and environmental reasons the LPG is used as well in vehicles as fuel.

To carry the LPG from the large storage tanks up to the intermediate reservoirs is used road transport with trucks. The risk of accidents with LPG increases substantially due to the inherent risk the carriage by road and the impossibility to control the surrounding environment through which the vehicle passes.

One of the main types of accidents with LPG tanks is the BLEVE (Boiling Liquid Expanding Vapour Explosion). This concept was first introduced in 1957 by Smith, Marsh and Walls from Factory Mutual Research Corporation (Center for Chemical Process Safety, 2010 p. 311).

Accidents involving pressure equipment are from the type technologic. They have consequences very serious for those who are in their neighbourhood due to the fluid pressure being released from an uncontrolled manner. The main consequences of the uncontrolled release of LPG from a portable tank are the formation of a shock wave, a fireball and the projection of fragments (Center for Chemical Process Safety, 2010 p. 320).

The measures of protection should be strengthened by several reasons including the fact that potentially affected people have no knowledge of the presence of danger, not have knowledge about the risks associated with, or even have not any knowledge about preventive or self-protection measures. In addition, everyone in the population can be affected by the effects of a BLEVE, namely children, adults, seniors and persons with limited mobility.

2. MATERIALS AND METHOD

The origin of knowledge included in this communication is from scientific papers published in journals, with referees and reference books, such as the CCPS (Center for Chemical Process Safety) or VROM (Ministry of Environment of the Netherlands). This methodology was used until 5 October 2011.

The research was conducted through communications Information System MetaLib@ and Google Scholar search engine, considering the following words: BLEVE, explosions and LPG, both in Portuguese, Castilian and English.

3. REVIEW OF LITERATURE, RESULTS AND DISCUSSION

3.1 BLEVE

T. Abbasi (Abbasi, 2010, p. 271) has considered the BLEVE as an explosion of physical type. However, due to the peculiarities of the causes of such explosions, they are classified separately from traditional physical explosions of bursting pressure equipment. The BLEVE is one of the most onerous type of explosion (Geneva, 2008, p. 110).

BLEVE was typified by the first time as an accident in 1957 by J. B. Smith, W. S. Marsh and W. L. Walls from Factory Mutual Research Corporation (Walls, 1978, p. 46). This phenomenon consists in a sudden release of a liquid or a liquefied gas after rupture of the tank which results in an instantaneous vaporization (Center for Chemical Process Safety, 2010 p. 311). For Walls (Walls, 1979, p. 22) the definition of this phenomenon consists in a major break from a reservoir into two or more of their components, when the liquid is at a much higher temperature than the boiling point at NTP conditions. For Birk (Birk, 1994, p. 474) a BLEVE is an explosive release of expanding vapor and boiling liquid when a container containing a pressure liquefied gas fails catastrophically. In the definition of these authors the concept is not introduced.

For several authors (Birk, 1993, p. 120) (Shaluf, 2007, p. 748) the BLEVE can be divided into three classes: BLEVE, hot BLEVE and cold BLEVE, depending on the type of event / mechanism. In figure 1 is described in the explanation of the phenomenon and its consequences.

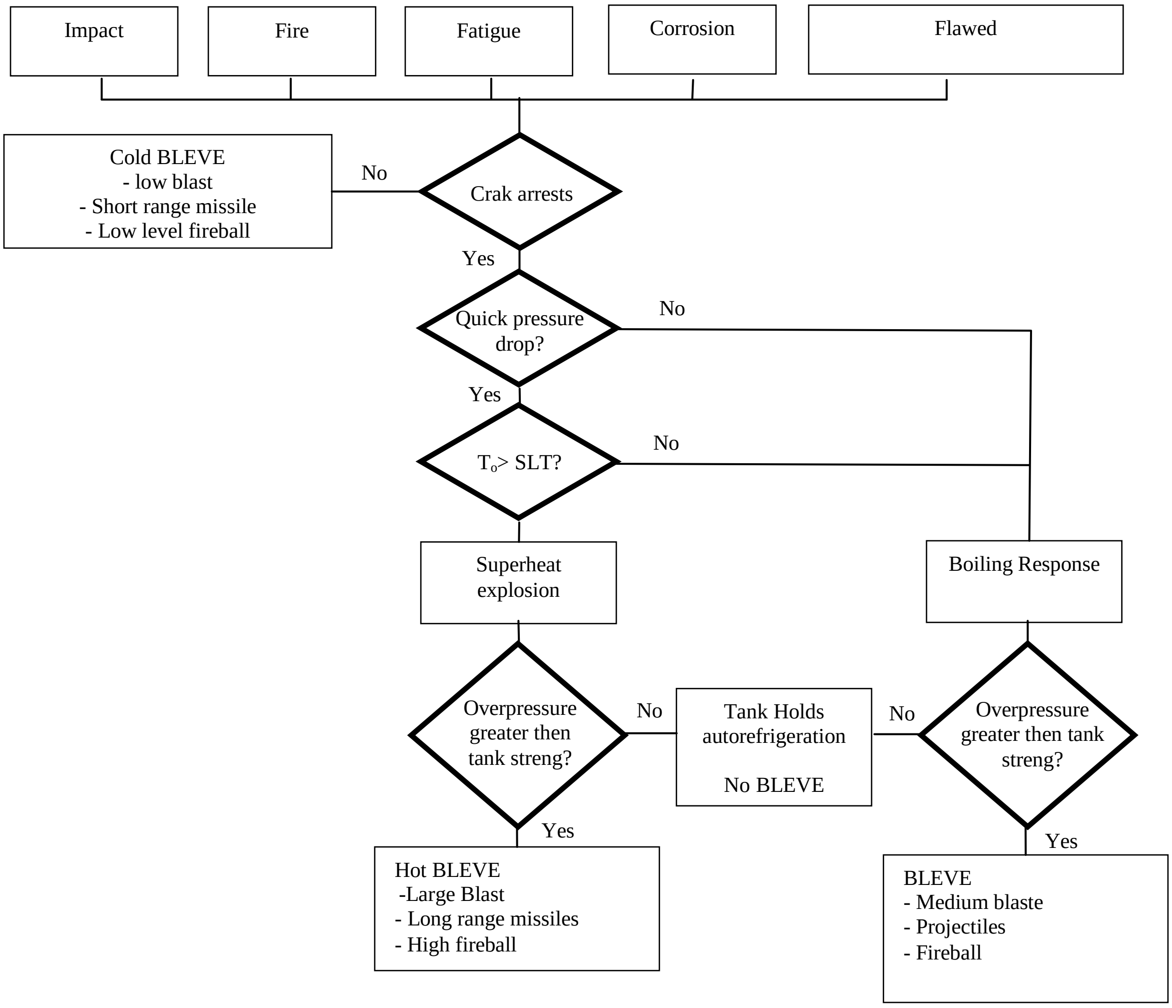

Figure 1 - Diagram of the process of BLEVE (Adapted Shaluf, 2007)

Reid presented a thermodynamic explanation for the phenomenon of BLEVE, through the theory of overheating limit , SLT (Reid, 1979, p. 1264). When there is a sudden decrease of pressure of a liquefied gas, this result in a change of state from liquid to vapor / gas without the fluid to have time to full boil. Thus the fluid passes into an overheated state when the fluid pressure is lower than the saturation pressure. Under these conditions the fluid enters in a zone of thermodynamic metastability (Mengmeng, 2007, p. 10). Thus, when the fluid moves to a position in the zone of metastability an explosion can occur, but not the BLEVE occurs (change A, Figure 2). The BLEVE can occur only when going to the unstable zone, ie when the spinodal line is crossed (change B of Figure 2).

The spinodal line, or boundary line of overheating, is defined by the points where the partial derivative of the equation of Van der Waals or Redlich-Kwong equation becomes zero, ie.

$$\left(\frac{\delta P}{\delta v}\right)_T = 0$$ Sallaa, Demichelab, & Casal, 2006, p. 693.

The temperature limit of overheating at atmospheric pressure can be calculated using the approximate formula SLT = $T_C[(0{,}11P/P_C)+0{,}89]$, where T_C is the critical temperature, P is atmospheric pressure and the P_C is the critical pressure (Prugh, 1991, p. 70).

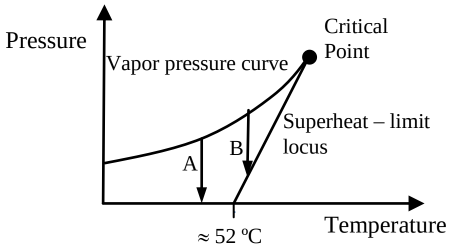

Figure 2 - curve / line limit overheating (spinodal) and propane vapour curve (Adapted - Reid, 1979, p. 1264)

On studies carried out by other researchers were found phenomena of BLEVE for temperatures below the temperature limit of overheating (Prugh, 1991, p. 15), (Birk, 1996, p. 236).
The causes for the rupture may be due to (VROM, 2005 p. 7.16):

- -the increase of the energy stored inside the tank to a value higher than the one for which it was designed;
- -the fact of the tank to have an external request higher than the projected.

A study conducted by Prugh to 49 BLEVE accidents, found that 17 of them were caused by exposure to fire, 12 due to faults in the mechanical resistance, 10 by overfilling, 6 due to chain reactions, 3 were caused by overheating and 1 by the steam explosion (Prugh, 1991, pp. 10-12).
This kind of accident has as results a shock wave with the projection of primary fragments (from rupture of the reservoir) and secondary (materials designed by the shock wave - glass, building materials, ...). If the released content, is fuel, may be also produced a fireball (Center for Chemical Process Safety, 2010 p. 320). In the human body, the shock waves can cause breakage of the internal elements such as lungs and eardrums and also the projection of people. The structures can also be damaged (VROM, 2003 p. 5). The fireball generated by the explosion may cause burns and fires.
The likelihood of a BLEVE is estimated by the HSE between 1×10^{-5} and $2,5\times10^{-5}$ occurrences per year (HSE - Health and Safety Executive, p. 33). The probability of a BLEVE in transportable tanks is less than 2.15×10^{-6} per year (Chakrabarti, 2011).

3.2 Consequences

The main consequences of a BLEVE are: Shockwave / pressure, projectiles and fireball.
When the shell bursts the energy released is distributed primarily by the last three parameters. These consequences of BLEVE are relatively well studied as a single phenomenon, but do not incorporate the surrounding environment.
In order to estimate the consequences of explosions BLEVE there are two main methodologies: the North American by CCPS (QA Baker), and by enterprise Dutch VROM (Van den Berg and Molag).

3.2.1 Pressure wave and projectiles

The calculation of the consequences of a BLEVE begins by determining the mechanical energy released. This energy is characterized by the pressure, by the mass and by the internal energy of the initial and final state, ie before and after the accident.

Consequences generated by the shock wave / pressure

Baker through the law of scale stemming from the law-Hopksion Cranz, will determine the distance scale $\bar{R}$

$$\bar{R} = \frac{R}{(E/P_0)^{1/3}}$$

Where *R* is the distance between the origin of the explosion and the point at which aims know the parameters, *E* is a fraction of energy released by the explosion converted into shock wave / pressure and P_0 is the atmospheric pressure.
With the distance value is determined the pressure rise and the impulse caused by the explosion.

Consequences generated by the projectiles through the empirical model of Baum's (Doormaal & Wees, 2005, p. 7.48)
The maximum speed (v) of the projectile can be calculated using the following equation

$$\mathbf{v} = \sqrt{\frac{0,08.E}{M}}$$

Where E is the energy released by the explosion and M the total mass of the reservoir.
After calculating the initial velocity will be determined the maximum radius reached by the projectile.

3.2.2 Fireball

To determine the consequences of the fireballs are calculated two parameters: the diameter (D) and duration (t) of the fireball. These two parameters are a function of the mass (m) of fuel in the tank. These functions vary with the values of the constants k_i, which take different values according to different authors. Abbasi, for example, has developed about 20 formulas, between 1973 and 1999 for the determination of the diameter and length of a fireball (Abbasi et al., Pp. 2007. 489-519).

$$D = k_1 m^{k2} \text{ e } t = k_3 m^{k4}$$

With the two previous parameters is possible to calculate the radiation received by a receiver (q) at a given distance from the center of the fireball.

$$q = \frac{2{,}2\tau RHm^{0{,}67}}{4\pi L^2}$$

Where: t is the atmospheric transmission, R is the fraction of heat radiated, m is the mass of fuel and L the distance from the center of the fire ball until the receiver.

3.3 Accidents in Southern Europe

In the Iberian Peninsula occurred two significant accidents both in Spain. In the Iberian Peninsula occurred two significant accidents both in Spain. One in July 11, 1978, in San Carlos, where a propylene leak caused 25 deaths and 211 wounded and another on June 22, 2002 with the release of 48 m3 of liquefied natural gas, LNG, in Tivissa, which resulted in one dead and two wounded.

The last reported incident occurred on June 29, 2009 with one train with fourteen freight cars of LPG in Viarreggio, Italy. 30 people died in this accident causing thousands of euros in property damage (Landucci et al., 2011).

3.4 Risk in traffic

The risk associated with this kind of transportation has increased gradually with increasing traffic (Van der Torn, pp. 2008. 343-379) and the quantities transported.

It is estimated that between 1940 and 2005 in the world died about 1,000 people, 10,000 has been injured and the property damage amounted to billions of euros (Abbasi et al., 2007).

The risk associated with an accident of the type BLEVE, in a static reservoir, is assessed based on the conditions of the reservoir at the time of rupture and characteristics of their content (VROM, 2005 p. 7.16). When the reservoir is subject to transportation, other factors are introduced. Among these are to emphasize the type of road, the traffic density and the population density of the areas through which passes (VROM, 2005 p. 1.1) .

3.5 Prevention of BLEVE

Research on the prevention of BLEVE, at the project level of the reservoirs / tankers, focuses mainly on two areas:

- Assessing the performance of safety valves
- Passive protection by improving the behavior of the reservoirs to heat.

One of the main lines of research on the performance of the road tankers to BLEVE is headed by Birk in Canada (Birk & Vandersteen, 2006, p. 648) and in Europe by TNO (Molag & Krruithof, 2005). This issue is so important that in 2006 was constituted an informal working group within the Economic and Social Council of the United Nations for the study and reduction of the BLEVE. The initiative was from Dutch government whose territory is crossed by one of the main routes of LPG road tankers (Gomes, 2008).

This group proposed technical measures (safety valve, thermal insulation, sunshades, aluminum ball inside the tank, additional protection against impact, ...) and organizational measures (periodic inspections, dedicated routes, speed control, training, management safety system, control of alcohol and drugs, ...). At present, the group continues to develop studies for which it was created, trying to find the most appropriate measures, taking into account their economic viability. The development of this study is expected to last until 2012 (Working Party on the Transport of Dangerous Goods - Economic Commission for Europe, 2011).

By improving the performance and reliability of safety valves will go to improve the flow of the fluid and thereby prevent rupture of the reservoirs by excess pressure (Pierorazio, et al., Pp. 2000. 60-65), (Jonathan, et al., pp. 2002. 227-236).

Improving the heat resistance of the tanks through coatings, will be increased the amount of time which the shell will resist to the collapse, allowing thus to take all necessary measures for evacuation of people and lessen the damage, with an estimated decline of the individual risk by 50% (Landucci, pp. 2009. 1182-1192).

The study of the behavior of tanks remains important, since, for market reasons the requirements of the building codes are decreasing, jeopardizing the safety of persons and goods (Birk, 2005 p. 55).

4. CONCLUSIONS

BLEVE is an technological accident that has serious consequences for people and property. It is caused by the pressure wave, by the projection of fragments and by the fireball (in case of fluid fuels). The probability of occurrence of such an accident is low. However, this probability increases when pressure devices are installed on mobile devices (road tankers). The trend to improve the prevention of BLEVE focuses on the construction of reservoirs, since the use of building codes, application of coatings and improving the efficiency of the safety valves.

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