BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. VI No. 3A/2008	69 - 74	Seria Tehnică

Investigation and Inquest Risk Management Systems for Boiling Liquid Expanding Vapour Explosion

Dumitru Paraschiv

Universitatea Petrol-Gaze din Ploieşti, bd. Bucureşti,39, Ploieşti
e-mail:dumitruparaschiv007@yahoo.com

Abstract

Reffering to the BLEVE – boiling liquid expanding vapour explosion – a BLEVE is the worst possible outcome when a propane or LPG tank is exposed to fire. BLEVE hazards include fireballs, blast, projectiles and possible toxic clouds or vapour cloud explosions.

Key words: *BLEVE, fireballs, blast, projectiles, toxic clouds, vapour*

Introduction

BLEVE – boiling liquid expanding vapour explosion – a BLEVE is the explosive release of expanding vapour and boiling liquid following the catastrophic failure of a pressure vessel holding a pressure liquefied gas such as propane or LPG. A BLEVE is the worst possible outcome when a propane or LPG tank is exposed to fire. BLEVE hazards include fireballs, blast, projectiles and possible toxic clouds or vapour cloud explosions. The phenomenon known as a Boiling Liquid Expanding Vapor Explosion (BLEVE) is the result of a liquid within a container reaching a temperature well above its boiling point at atmospheric temperature, causing the vessel to rupture into two or more pieces. A BLEVE can occur when fire impinges on the LP tank shell at a point or points above the liquid level of the contents of the LP tank. This impingement causes the metal to weaken and fail from the internal pressure. BLEVEs can result from mechanical damage to a tank, as well. This damage can be the result of a train derailment, traffic accident, or other physical shock. When a BLEVE occurs, debris may travel hundreds of feet, with tremendous force, and the escaping fuel can ignite causing an expanding fireball.

Two-Step Slow BLEVE

In this case there is a significant time between when the original fissure opens and when the tank fails catastrophically. First a small hole forms in the vapour space wall and this leads to a pressure drop which then causes a liquid boiling response that causes pressure recovery in the tank. This pressure recovery drives the crack along the length of the tank to cause the total loss of containment and BLEVE. In this case the crack velocity may be as low as 1 m/s.
If you responded to a LPG or propane tank fire incident, you would want to know things like, how long it should take the fire to empty the tank through the pressure relief valve, or how big

the fireball would be if the tank failed. You would like to have some idea of the likelihood that the tank will fail and when. The tank thermal model is a detailed computer simulation of a pressure vessel in a fire. This computer model accounts for the following processes. The user can run the tank thermal model to get an estimate of how the tank will respond to various types of fire exposure. The software analyzes engulfing or partly engulfing pool fires, remote pool fires and even torch fires. The input for the thermal model has been simplified and streamlined. The software estimates critical times such as time to tank failure or time to empty for a tank under fire exposure. With the tank thermal model you see how the tank changes over time when it is exposed to fire, including:

- tank internal pressure
- liquid fill level
- wall temperatures
- tank stress and strength

Fig.1. Tank Thermal Model.

With the tank thermal model it is possible to get an estimate for the time frames involved with different fire conditions, tank scales, fire types and thermal protection. You will develop a better understanding of how a tank responds to fire exposure. If a sufficient amount of water cannot be applied to the tank safely, then fire fighters should be withdrawn to a safe remote location, and fire should be allowed to burn.

Single-Step Rapid BLEVE

The figures show the BLEVE of a 400 litre propane tank (non- ASME code) exposed to torch fire impingement from above. In this case the tank has a 3 mm wall rather than the 6 mm needed to be an ASME code tank. This tank failed so rapidly that the liquid flashing had little or no role in the tank failure. In other words, the vapour energy was sufficient to drive the failure crack the full length of the tank. In this case the crack velocity was of the order of 150 m/s. In each of these incidents, the relief valves were operating upon arrival of fire department. The weakened tank shells ruptured sending tank pieces in all directions striking near-by buildings, equipment and personnel. Therefore, it should not be assumed that because the relief vents are operating, a BLEVE would not occur. When flames are impinging on an LP tank, there is no safe side or end to approach. In a BLEVE, sections are thrown in all directions. The potential for a BLEVE should be considered any time there is direct flame impingement on a LP-Gas vessel at the vapor space of the vessel, when venting through relief valves is not adequate to relieve the pressure build-up. Since it is difficult to detect if the venting is adequate in an emergency situation, the potential of a BLEVE should always be given the utmost consideration. The most effective way to reduce the potential of a BLEVE is to apply large quantities of water to the effected tanks, to cool the vessel. This evolution requires that large amounts of water be readily available and for extended time periods. Unattended hose stream or monitor devices should be utilized to complete this task. The rapid phase change can also produce strong thrust forces that can propel the tank over large distances. If the contents are flammable then immediate ignition will result in a fireball or flash fire. Delayed ignition could lead to a vapour cloud explosion**.**

Fig.2. The potential for a BLEVE

Transient Jet Release

If the tank has not been weakened sufficiently then a BLEVE does not take place after thermal rupture is initiated. In this case the fissure does not run the entire tank length but is arrested in strong material. In this case the tank contents vent as a two-phase transient jet. If the hole is large (i.e., the hole length is of the order of the tank diameter) then the release looks very much like a BLEVE (i.e., all contents vent in a fraction of a second, large fireball, tank may rocket). Another way to say this is that the energy in the liquid and vapour was not sufficient to keep the crack moving along the tank. In this case the tank contents would have vented rapidly through the large opening. This jet would have been both liquid and vapour and it would have produced a very large but short duration jet fire. This jet produces a large thrust force and in some cases the tank could be propelled over some distance. The next figure shows the case of a finite failure where the tank did not BLEVE. In this case the tank was strong enough to stop the crack from travelling the full length of the tank. Another way to say this is that the energy in the liquid and vapour was not sufficient to keep the crack moving along the tank. In this case the tank contents would have vented rapidly through the large opening. This jet would have been both liquid and vapour and it would have produced a very large but short duration jet fire. This jet produces a large thrust force and in some cases the tank could be propelled over some distance.

Fig. 3. The case of a finite failure where the tank did not BLEVE.

Fireballs from BLEVEs

However, now that carbon dioxide and its mixtures are being used under pressure for gas and oil recovery, carbon capture and storage and supercritical fluid processes, BLEVE must again be considered. This involves calculating the range of conditions of pressure and temperature where BLEVEs can occur. Even under these conditions a BLEVE is unlikely but, because of the enormity of BLEVE explosions, it is prudent to avoid these conditions. In fact failure to avoid BLEVE conditions is quite inconsistent with the current safety culture in oil and gas companies.

The shape and liftoff of BLEVE fireballs vary significantly and depend on the detailed thermodynamic state of the liquid, and the details of the tank failure. If the tank fails rapidly then classical spherical fireballs result. If the failure is slow then the initial jet release sends the fireball high in to the air. If the liquid is relatively cool then a large ground fire is possible. These differences can change the hazards to nearby objects (such as emergency responders) significantly. Why do BLEVEs occur? A theory developed by Professor Reid and colleagues at MIT (M.E. Kim and R.C. Reid, ‘ The rapid depressurization of hot, high pressure liquids or supercritical fluids’ in *Chemical engineering at supercritical fluid conditions*, edited by M.E. Paulaitis, Ann Arbor Science, 1983) shows that a very spectacular physical event must occur under certain circumstances, and this is likely to be the explanation of BLEVEs.
Some tests were specifically designed to study the boiling liquid expanding vapour explosion or BLEVE as it is commonly known. In all cases the tanks and surroundings were heavily instrumented to measure tank and lading temperature distributions, tank internal pressure, high speed transient presssures during failure, and far field thermal radiation and blast overpressure.
Liquid Energy Variation during fire engulfment of a propane tank
The graph shows that peak liquid energy is reached when liquid temperature stratification is dissipated by pressure relief valve action. If the tank fails at peak energy then a BLEVE is most likely. Note that in this case the tank failed well after the peak energy was reached. This tank did BLEVE.

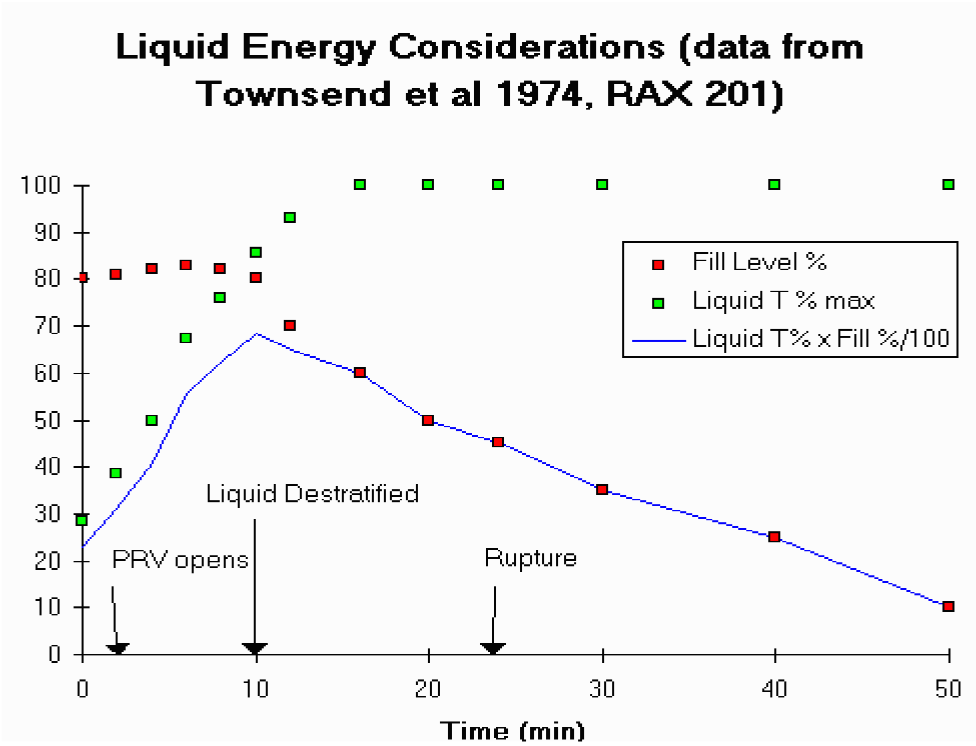

Fig. 4. Liquid Energy Considerations.

This graph shows how engulfment fraction affects the time to peak energy. For a given tank there may be an engulfment fraction that causes a tank to fail just as its peak energy is reached. This would give the worst hazard for this given tank. The source term for an accident sequence expresses ’how much’, ’for how long’ and in ’what form’. The source term for a warehouse fire defines two parameters - the rate of release of dangerous substances into the smoke plume as a function of time and the buoyancy of the plume. These in turn depend on the rate of combustion, the rate of seeding of parent compounds and the rate of heat released to the atmosphere. All are difficult to calculate and should be based on conservative assumptions.

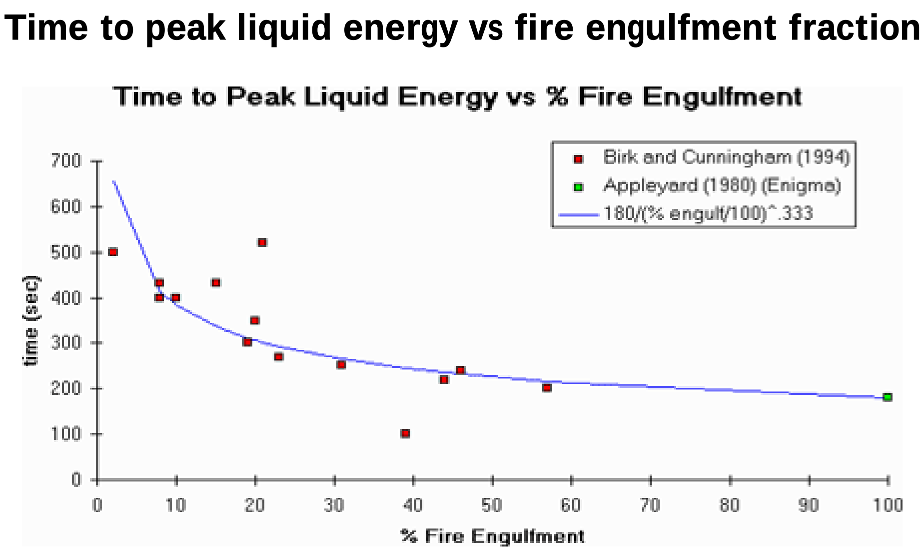

Fig. 5. Time to peak liquid energy.

Assessors can use the following questions to test the adequacy of the source terms used in the consequence analysis.

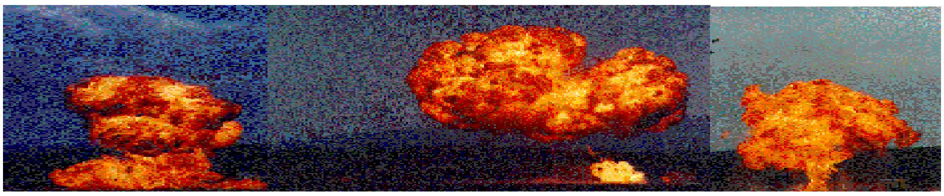

Fig. 6. The source term for a warehouse fire.

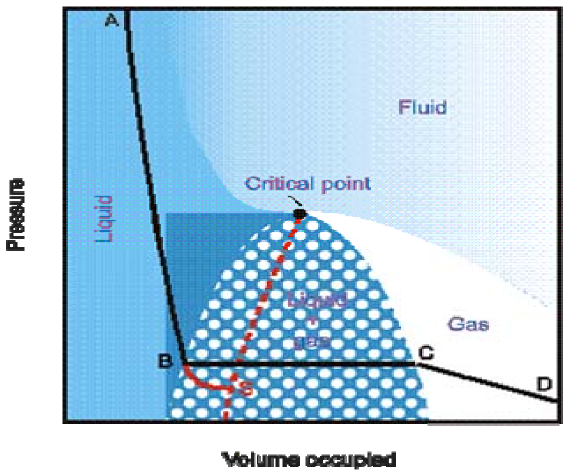

Fig. 7. Analysis based on an average inventory taking

A simplified explanation of this theory can be given with the aid of the figure below, which is a diagram of the relationship between the pressure in a substance and the volume it occupies as a liquid, gas and fluid.

The continuous thick black line **ABCD** shows the behaviour of the substance at a constant temperature and at thermodynamic equilibrium. In the section **AB**, the substance is a liquid and as the volume it occupies is expanded the pressure falls dramatically.

Eventually the pressure falls to the vapour pressure of the liquid at the particular temperature at **B**. The liquid then starts to evaporate to become a liquid-gas mixture, and the pressure stays constant at the vapour pressure. Eventually it reaches **C**, where the liquid has been completely converted to gas. The pressure then drops as it is expanded further.

Once the spinodal curve is reached separation into liquid and gas **must** occur. The density variations develop spontaneously into liquid and gas regions. This occurs homogeneously throughout the whole liquid. The rise in pressure on to the vapour pressure line **BC** is not large but it happens at great speed, homogeneously and at time scale of molecular motion. The shock to the containing vessel is huge and a disastrous BLEVE happens.

The other factor greatly affecting ground level concentrations of toxic substances down wind of a burning warehouse is the heat content of the smoke plume. Fire analysis for a COMAH safety report should assume that no more than 0.4 of the heat of combustion is retained. Accident consequences based on a buoyant plume dispersion model in which more than 40% of the heat of combustion remains in the smoke released to the atmosphere may be considered optimistic.

The effect of blast should also be quantified in terms of the number of buildings in each of several damage categories. The effect of wind direction on the number of casualties should be addressed, and the accident analysis should take into account the effect of other variables such as time of year, time of day, day of the week and rain if they have a significant effect on the off-site consequences.

Its buoyancy number, the windspeed, the atmospheric stability class and the height of any inversion layer govern the rise of a smoke plume. Plume buoyancy increases as the fire spreads through the warehouse while the other parameters are constants.

References

1. Paraschiv D. – *Identificarea, evaluarea şi cuantificarea riscurilor tehnic şi tehnologic în transportul feroviar al HGL*. Referat de Doctorat nr. 4. Ploieşti, Editura „UPG”, 2005.
2. Bukowski R. W. – Risk and Performance Standards. Research Engineer, Building& Fire Research Laboratory, NIST, SUA, 2003.
3. Henly E. J., Kumamoto O. – *Reliability Engineering and Risk Assessment Pretince-Hall*, Englewood Cliffs, N.J. 1994.
4. Ilincă C., Paraschiv D. - *Managementul riscului tehnic şi tehnologic – Risc tehnic/tehnologic în transportul feroviar al HGL*. Focşani, Editura „Terra”, 2006.

Investigarea şi anchetarea sistemelor de gestionare a riscului exploziei vaporilor produşi de expansiunea lichidului de fierbere

Rezumat

Cu referire la BLEVE – Explozia Vaporilor produşi de Expansiunea Lichidului la Fierbere – BLEVE este cel mai rău posibil rezultat atunci când tancurile/rezervoarele de propan sau LPG sunt expuse la foc. Hazardul BLEVE include mingii de foc, balistica, proiectile şi posibili nori toxici ori nori de vapori explozivi.