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Blast overpressures from medium scale BLEVE tests

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Abstract

The measured blast overpressures from recent tests involving boiling liquid expanding vapour explosions (BLEVE) has been studied. The blast data came from tests where 0.4 and 2 m^3 ASME code propane tanks were exposed to torch and pool fires. In total almost 60 tanks were tested, and of these nearly 20 resulted in catastrophic failures and BLEVEs. Both single and two-step BLEVEs were observed in these tests. This paper presents an analysis of the blast overpressures created by these BLEVEs. In addition, the blast overpressures from a recent full scale fire test of a rail tank car is included in the analysis.

The results suggest that the liquid energy content did not contribute to the shock overpressures in the near or far field. The liquid flashing and expansion does produce a local overpressure by dynamic pressure effects but it does not appear to produce a shock wave. The shock overpressures could be estimated from the vapour energy alone for all the tests considered. This was true for liquid temperatures at failure that were below, at and above the atmospheric superheat limit for propane. Data suggests that the two step type BLEVE produces the strongest overpressure. The authors give their ideas for this observation.

The results shown here add some limited evidence to support previous researchers claims that the liquid flashing process is too slow to generate a shock. It suggests that liquid temperatures at or above the Tsl do not change this. The expansion of the flashing liquid contributes to other hazards such as projectiles, and close in dynamic pressure effects. Of course BLEVE releases in enclosed spaces such as tunnels or buildings have different hazards.

Keywords: BLEVE; Blast overpressure; Shock

1. Introduction

If a tank containing a pressure liquefied gas (PLG) ruptures there are two possible outcomes:

(i) Partial failure with finite rupture and transient single or two phase jet release
(ii) Complete rupture with total loss of containment (TLOC) and BLEVE

BLEVE stands for, boiling liquid expanding vapour explosion. Reid (1979) suggested that for a BLEVE to take place, the sudden pressure drop must take the liquid to the superheat limit spinodal Carey (1992) so that homogeneous nucleation takes place in the bulk liquid. If the definition of a BLEVE requires homogeneous nucleation then it is possible there has never been a real BLEVE. If we define a BLEVE as simply a "boiling liquid expanding vapour explosion" then we do not need homogeneous nucleation. We have observed many explosions from the TLOC of propane pressure vessels. We do not think any of them involved bulk homogeneous nucleation.

In this paper we will use the following definition of a BLEVE:

A BLEVE is the explosive release of expanding vapour and boiling liquid when a container holding a PLG fails catastrophically.

A key word here is catastrophic failure. In this case catastrophic failure means the tank is fully opened to release its contents nearly instantaneously. The BLEVE does not cause the tank rupture. The BLEVE results from the sudden opening of the vessel. In most cases this means the tank is flattened on the ground after the BLEVE and parts (e.g., tank end caps) may be thrown over large distances.

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A BLEVE generates hazards including shock overpressures, high velocity expanding vapour and flashing liquid, projectiles and release of the contained PLG. If the PLG is flammable then there is a fire or explosion hazard. If the material is toxic then there is an exposure hazard.

A TLOC of a PLG vessel can take place for a number of reasons including: flawed materials, fatigue, corrosion, poor manufacture, thermal stresses, pressure stresses and reduction in material strength due to high wall temperatures. Any one of these could result in a TLOC. However, in most accidents it is a combination of several of the above factors that add up to cause the failure of a vessel.

A BLEVE is a physical explosion that follows the sudden loss of containment of a PLG. When a PLG experiences a sudden pressure drop (due to loss of containment) the bulk of the liquid is sent into a state of superheat. If the degree of superheat is large it causes rapid and violent flashing of the liquid. Generally speaking, a large degree of superheat requires a very rapid pressure drop.

Researchers have shown that BLEVEs can take place without reaching the superheat limit. However, it has been shown (see for example Barbone, Frost, Makis, & Nerenberg, 1994) that the flashing response to the sudden pressure drop will be most powerful if the atmospheric superheat limit is reached. In real world pressure vessels with rough internal surfaces and with liquid with impurities and pre-nucleation of bubbles, reaching the superheat limit is very unlikely. Heterogenous nucleation starts well before the superheat limit is reached.

There is coupling between the tank failure and the fluid properties. When a vessel begins to rupture the growing fissure acts like a relief valve and this triggers outward flow and a pressure drop in the vessel. This leads to liquid flashing and a pressure transient in the vessel. Birk and Cunningham (1994) presented a BLEVE map based on fire tests of 400 L propane tanks. This map showed that the strength of the tank and the liquid fill level and temperature determine if a tank will BLEVE or not. For tanks severely weakened (e.g., by fire or by severe corrosion) a BLEVE can take place with the propane at ambient temperature. In these cases the vapour space energy may be sufficient to drive the tank to catastrophic failure. However, as the tank strength increases, the liquid energy must play a more important role in the tank failure process. With high liquid fills and temperature, any rupture that forms results in strong flashing of the liquid. This flashing causes pressure recovery in the tank and this can drive the tank to catastrophic failure and BLEVE.

This paper is about estimating overpressures generated by BLEVEs. In a recent paper, van den Berg, van der Voort, Weerheijm, & Versloot, (2006) looked at numerically calculating BLEVE overpressures assuming near-instantaneous releases of liquid. They did this by solving the Euler equations in various domains. This is very valuable. We need these detailed analytical tools. However, we also need simple calculation procedures to estimate BLEVE hazards. This paper is about simple analysis techniques.

The literature presents techniques to estimate BLEVE overpressures as a function of the PLG properties, the vessel size, and the distance to the target. Many of them use the liquid energy to predict the BLEVE overpressure. However, evidence in several references (see for example AIChE Centre for Chemical Process Safety, 1994; Baker, Cox, Westine, Kulesz, & Strehlow, 1983) point to the fact that the shock overpressure from BLEVEs is relatively low and that data suggest that the liquid phase change does not generate a shock. For this reason most published methods grossly overestimate the BLEVE overpressure, especially in the near field.

2. Sequence of events

Let us consider a case where a pressure vessel is partially filled with a PLG and its vapour. For the liquid to be a PLG it must be stored at an elevated pressure at ambient temperature. This means the liquid is at a temperature above its normal atmospheric boiling point.

If a small hole forms in the vapour space wall of this tank then vapour will escape. This causes a small pressure drop which sends the liquid into a small degree of superheat which then causes some of the liquid to flash to vapour. This will take place near the liquid surface at the tank wall where there are nucleation sites for boiling. The newly generated vapour will act to maintain the pressure in the vessel. The generation of vapour takes heat energy from the liquid. Overtime the venting and boiling process cools the liquid and the pressure and temperature in the vessel will decrease.

If the hole is large then the vapour mass flow thought the hole will be large and the pressure drop will be greater and more rapid, resulting in more superheat, and stronger flashing. With strong flashing the liquid height will swell significantly due to the vapour bubbles rising through the liquid. The flow out of the vessel will probably entrain liquid droplets (i.e., two-phase flow) thus increasing the mass flow and thrust forces.

If the vessel opens fully and rapidly, then the vapour space energy will be released suddenly and a shock wave will be produced. This shock will move out into the surroundings at supersonic speed. The sudden loss of the vapour space will send the liquid deep into a state of superheat. The liquid will respond with a powerful flashing response. This is a BLEVE. The question is, does the liquid phase change produce a shock? Is the liquid phase change an explosion? This is still a question.

3. Single and two-step BLEVEs

BLEVEs have been observed (Birk, Cunningham, Ostic, & Hiscoke, 1997) where the tank failure process is very rapid. One moment the tank is there, and next moment it is gone. In regular video this means the tank is there in one