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ANALYSIS OF BLEVE FORMATION DANGER FACTORS DURING LPG STORAGE

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Summary.The analysis of approaches to modeling and evaluation of processes prior to the appearance of the BLEVE effect during accidents of LPG tanks was carried out. The BLEVE effect is one of the worst-case scenarios for the development of an accident, so the effective assessment of this effect, as well as the prediction of its consequences, is an integral part of the safety risk assessment.The results from the various sources considered suggest that it is the vapour energy that is the source for the shock wave from BLEVEs. The immediate hazards of a BLEVE are a blast and projectiles. Since LPG is flammable, it will be ignited immediately and a fireball is possible with the associated hazards of fire engulfment and thermal radiation.

Keywords: Liquified Petroleum Gas (LPG),Boiling Liquid Expanding Vapour Explosions (BLEVE), fireballs, catastrophic pressure vessel failure.

Introduction. Liquefied gas fuel is widely used all over the world.Their use can lead to accidents with major consequences. Major accidents have occurred in many countries. In Europe, the Seveso accident in 1976 prompted legislation to prevent and control such accidents. In 1982, the first EU Directives 82/501/EC - the so-called Seveso Directives were adopted. The directives were later replaced by Council Directives 96/82/EC and 2012/18/EC, the so-called Seveso II and Seveso III Directives [1].

The international definition of liquefied gas is Liquified Petroleum Gas (LPG). LPG is a hydrocarbon fuel consisting primarily of propane or butane alone or as a mixture. It is stored in tanks in a liquid state and is heavier than air, and tends to accumulate at the bottom. In the liquefied state, the volume occupied by the gas is approximately 260 times smaller than in the gaseous state. It disperses more difficultly than natural gas, so it is more prone to ignition or explosion in the event of a leak.

The percentage ratio of propane and butane depends on the season and climatic conditions. As a rule, this ratio is fixed in the "national standards" of a specific region or country of use. In the cold season at temperatures below +10^{0}C, the volume of propane should be at least 75-80%. In the warm season, the proportion of propane in the mixture should be no more than 40%, because at high temperatures, a mixture with a low propane content is more effective. Cylinders and tanks are filled to no more than 85% of their geometric volume [2].

Wide use of liquefied hydrocarbon gases (LPG) determines the use of tanks for storage and transportation of these products in various industries. Tanks with LPG are highly dangerous, which is confirmed by major incidents involving them. Often, these incidents follow a scenario where the tank is exposed to a fire source, as a result of which a tank explosion with catastrophic consequences is possible [3].

In case of accidents at LPG and oil products storage facilities, one of the dangers is the occurrence of a combustion source. In this case, due to the long preparation for localization and fire extinguishing, the storage objects are strongly heated, which can lead to BLEVE (Boiling Liquid Expanding Vapor Explosions) and the formation of secondary lesions [4].

Main part. Fire exposure of storage and transportation vessels of hazardous materials (including pressure liquefied gases) can result in BLEVEs and other high-consequence incidents with large societal and economic impacts. To reduce risk most countries have numerous regulations, codes of practice and guidance notes covering the design, operation and maintenance of vessels and thermal protection systems [5].

The primary source of danger for liquefied gas is fire. Both propane and butane can ignite relatively easily from a flame, spark, or static discharge. Igniting clouds of butane or propane often results in explosion-like damage, especially if the vaporization occurred in an enclosed space [6].

Among the most devastating of accidents likely in chemical process industry is the boiling liquid expanding vapour explosion (BLEVE). It is accompanied by highly destructive blast waves and missiles. In most situations there is also a fireball or a toxic gas cloud.The damaging effect of BLEVEs is reflected in the fact that the 80-odd major BLEVEs that have occurred between 1940 and 2005 have claimed over a 1000 lives and have injured over 10,000 persons besides harming property worth billions of dollars [7].

During a large-scale fire, tanks located directly near the geometric center of the strait fire are exposed to high thermal radiation, which can cause the BLEVE effect and lead to the emergence of secondary lesions. For example, the accident described in [6]. In 1984, a major fire and a series of explosions occurred at a liquefied hydrocarbon gas terminal in Mexico. Due to the leakage of LPG, which caused explosions and fire, after 5 minutes the first BLEVE phenomenon appeared. After 1 min. – another one, with the appearance of a fireball. Drops of LPG fell from the fireball onto the territory of the terminal. Over the next hour, there were 15 more explosions. BLEVE occurred on most spherical and cylindrical tanks. Cylindrical tanks weighing 20 tons were thrown by the explosion to a distance of 100 m, and one even 1200 m.

The most dangerous situation can occur in the event of a rupture of the container due to the explosive release of vapors. The likelihood of this occurring spontaneously is very low, as modern LPG tanks are designed to maintain structural integrity at internal pressures 7 or 8 times normal operating pressure and 4 times the opening pressure of the tank relief valve. Conditions that pose a threat to the structural integrity of the container usually occur as a result of a long-term effect on the steam-air space of the tank lining of a direct flame [8].

As the heat of the fire is transferred through the wall of the container, the temperature of the liquid product will rise rapidly, the liquid will begin to evaporate, increasing the pressure inside the tank. Overtime, the pressure in the tank will reach a point that threatens its integrity. To prevent reaching this point, the system is equipped with one or more safety valves that open when the internal pressure reaches a set level and thereby control the release of product vapors to the atmosphere and release the pressure inside the tank. One of the main dangers is that accidentally spilled hydrocarbons can ignite and heat the LPG container, which will increase its temperature and pressure due to the basic ideal gas law. If the fire is long enough and intense, the pressure created by the boiling and expansion of the gas canexceed the valve's ability to release the excess.

If the tank ruptures, a certain amount of steam can escape rapidly, depressurizing the tank and releasing an excess pressure wave from the point of rupture. Such a sudden release of pressure inside the tank causes intense boiling of the liquid, during which a large amount of vapors are released. The pressure of this vapor can be very high, causing a second, much more significant overpressure wave (BLEVE).

For the BLEVE analysis, a realistic explosion of a small refractory tank for liquefied hydrocarbon gas was carried out at the Braunschweig VAM test facility. During the fire test, a railway tank containing 10 m^3 of propane was exposed to fire. 2 minutes after the start of the test, the pressure in the railway tank began to increase. After 15 minutes, when the pressure reached about 25 bar, the rail tank exploded with a BLEVE. The temperature of parts of the tank damaged by fire during the explosion was approximately 500^0C [8].

Risk assessment studies carried out in the Netherlands have shown that due to an explosion of boiling LPG liquid vapor (BLEVE) in a tank under the influence of an external fire source ("hot" BLEVE), the estimated risk values for the public are exceeded by 25%. "Hot" BLEVE mainly occurs as a result of a decrease in the strength of the walls of the tank in its upper part at a temperature above 500 ^{0}C, which is achieved under the influence of the heat emitted by the fire. Heat radiation and the blast wave in the case of a BLEVE can lead to very serious consequences for people who are within a radius of 500 − 700 m from the accident site. If no additional measures are taken, a BLEVE occurs 25 minutes after exposure to fire [9].

The BLEVE effectis observed in the case of a catastrophic failure (destruction, damage) of a tank with liquefied gas under pressure. As a rule, parts of the container fly away (scatter) as a result of this effect. An aerosol from a mixture of matter and air can ignite immediately, the flame front will quickly spread from the point of ignition, forming a fireball, the temperature of which is extremely high.

Probable consequences of accidents with the BLEVE effect indicate that a fireball with flying debris will be observed, which increases the threat of further development of the emergency situation. Therefore, explosions of this type are most dangerous during fires near containers with liquefied gases.When the BLEVE effect occurs on the tank, it is most likely that a fireball with fragments will be observed (68%), a fireball will be observed less likely (19%), and fragments will be less likely to fly without the formation of a fireball (13%) (Fig.1).Thus, for a BLEVE event on a tank, there is an 87% chance of a fireball occurring [10].

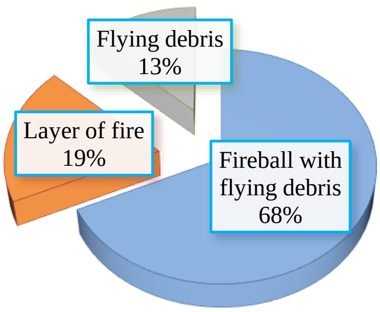

Fig. 1. **Possible consequences of the accident**

The works [11...15] describe the chain of events in typical BLEVEs. In most cases the first step will be that a vessel containing a gas that has been liquefied by pressurization (PLG) gets accidentally exposed to heat (most often a fire). The next step is that the vessel suddenly fails due to the increased internal vapour pressure and the weakening of the vessel material. The resulting very sudden depressurization of the hot liquid gives rise to intense, often volumetric, evaporation. The very rapid evaporation in turn gives rise to powerful blast wave emission (Fig. 2).

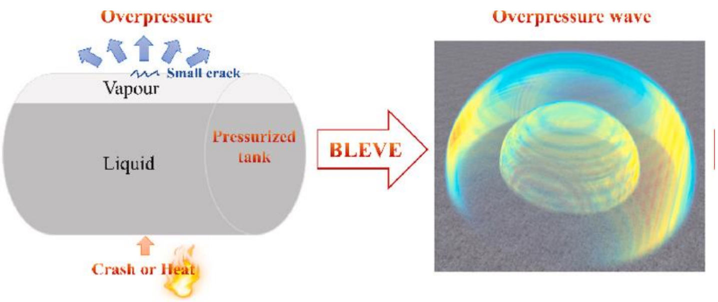

Fig. 2. **BLEVE emergence model**

If the evaporated liquid is combustible and gets ignited, a huge fire ball will most often be generated.

The destruction of the initial container may cause propelling of high-speed debrises, which when hitting other PLG containers may give rise to secondary BLEVEs. The remaining part of the combustible liquid from a container, that has not evaporated will, when ignited, give rise to a fire.

The blast over pressures from tests in volving boiling liquid expanding vapour explosions (BLEVE) has been studied [13]. The explosion data was obtained from tests in which 0.4 and 2 m^3 propane tanks were exposed to torches 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.

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.

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

✓ Partial failure with finite rupture and transient single or two phase jet release.

✓ Complete rupture with total loss of containment (TLOC) and BLEVE.

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

A BLEVE generates hazards including shock overpressures, high velocity expanding vapour and flashing liquid, fragments 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.

The experiments [16] indicate that crack development and propagation during vessel failure occurred in two distinct steps:

- a rupture stage, where a crack opens up and becomes stable forming an opening for a vapour or two-phase jet discharge;
- a final fast fracture stage, where the initial crack rapidly propagates into the metal as a plain stress shear failure along (usually) the entire length of the tank and then circumferentially at the end caps.

The consequence of this type of failure is called a BLEVE. The process causes the remaining contents of the vessel to be rapidly released as a superheated liquid aerosol which may then ignite and form a fireball.

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.

The results from the various sources[7….9] considered suggest that it is the vapour energy that is the source for the shock wave from BLEVEs. This shock produces the explosion noise and causes the near and far field shock damage. Usually, the damage caused by the shock from a BLEVE is small compared to the damage potential of fireballs, projectiles and close in dynamic pressure loading from the flash vapourization.

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