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Multiple BLEVE's and fireballs of gas bottles: Case of a Russian road carrier accident

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ABSTRACT

The scenarios of multiple BLEVEs (Boiling Liquid Expanding Vapor Explosions), characteristics of multiple explosions and fireballs of flammable gas bottles are investigated within the context of a recent Russian road carrier accident. The applicability of available semi-empirical equations (models) to estimate the explosion overpressure and fireball characteristics e.g. diameter, elevation, Surface Emissive Power, irradiances, thermal safety distances and missile/projectile distances are evaluated. It is shown that the existing models are valid only for a scenario of single event of BLEVE and fireball. Hence, characterization of multiple BLEVEs and fireballs require appropriate estimation of an equivalent mass that actually contributes in the overall hazard. Such an equivalent mass helps to use the existing models and establish the safety distances that match the observed reality on the site very well.

1. Introduction

Multiple BLEVEs and fireballs are the probable scenarios of storage and transportation accidents occurring with flammable gasses and liquids. A number of works have been published before on experimental as well as computational investigations carried out with single BLEVE and fireball (Mannan, 2005; van den Bosch and Weterings, 1996; Casal et al., 2001; Dorofeev et al., 1995; Makhviladze et al., 1999; Baum and Rehm, 2005; Luther and Mller, 2009; Reniers and Cozzan, 2013; Mishra et al., 2015). However, studies on multiple BLEVEs and fireballs are rare and did not receive much of attention in the past even though they represent one of the worst-case scenarios (domino effect). The reasons behind lack of studies is the difficulty in reproducing the scenario at the lab scale. For instance the assessment of impact energy due to collision, topographical reproduction (obstacles, confinement and terrain), type and duration of primary spill, kind of ignition and most importantly the responses of metal and insulating materials to the fire loading all can have significant alterations to the considered scenario (Mannan, 2005; Baum and Rehm, 2005; Luther and Mller, 2009; Mishra et al., 2015). Therefore, instead of replications of accidents it seems reasonable to study the occurred accident, the predominating factors and eventually summarizing the lessons learned. In the present work such a study is performed on a truck (carrying propane gas bottles) crash to a preceding van (http://cars.aol.co.uk/201, 2014; http://www.publicsafetyre, 2014; http://www.autoevolution.). The occurrence of multiple BLEVEs and fireballs are described and influencing safety relevant parameters are discussed.

2. The incident

On 13 July 2013, a truck on a Russian highway in Moscow, carrying 36 propane bottles collided to a preceding van leading to spillage of engine fuel (diesel), ignition, engulfment of truck in a developing diesel pool fire (diameter ~10 m) and occurrence of multiple BLEVEs and fireballs (Fig. 1) (http://cars.aol.co.uk/201, 2014; http://www.publicsafetyre, 2014). The accident clearly demonstrated the existence of a worst-case scenario simulating a transportation accident likely to happen with flammable gas bottles. A total of 36 explosions and fireballs were heard and seen one after the other and also overlapped sometime. Furthermore, the flying cylinders and projectiles (missiles) led to an even more disastrous consequences to the nearby region in a radius of over 0.3 km. Fortunately, no fatalities were reported including the driver who left the place just after the crash (http://www.publicsafetyre, 2014; http://www.autoevolution.). However, such accidents are

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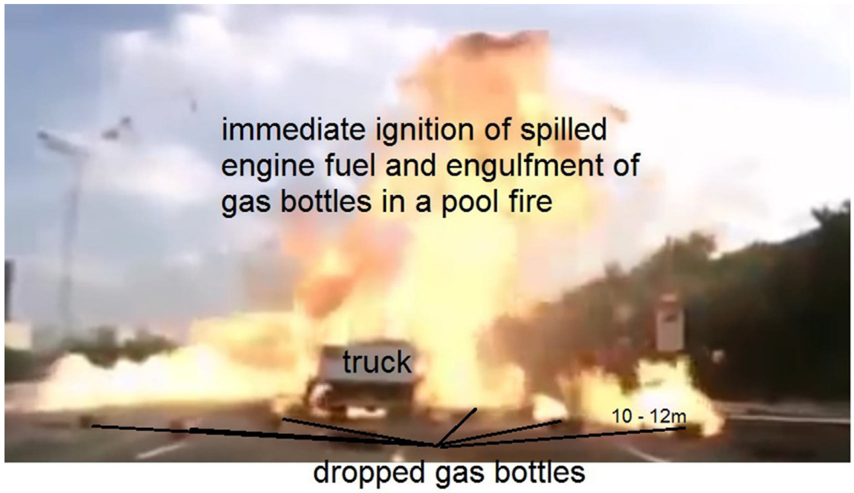

Fig. 1. Spill of diesel fuel after the collision, subsequent ignition and engulfment of carrier in a pool fire.

likely to occur also in a populous areas where precise safety distances from events of multiple BLEVEs and fireballs are necessary to develop. The applicability of semi-empirical models valid for single BLEVE and fireball to multiple BLEVEs are verified and further suggestions on considering an equivalent mass of involved fuel for such scenarios are given.

3. Observed and predicted characteristics of multiple BLEVE's

3.1. Safe overpressure distance, z

One of the most important characteristics of a multiple BLEVE event is the explosion overpressures generated due to a series of explosions occurring individually (stand alone mode) or in an overlapped mode. Consideration of later will increase the safety distances to a large extent than the former one. Here, both events are analyzed and already established equations are applied to estimate the effective safety distances.

For a safe overpressure limit e.g. 5 kPa, the observed and model predicted distances for the three scenarios i.e. one, all and equivalent masses (cylinders) are listed in the first column of Table 1 and are shown in Figs. 2 and 3, respectively. The minimum observed safety distance from explosion overpressure was about 15–37 m (calculated by considering the velocity of projectiles $v = \sqrt{(2gh)/\sin\theta}$; h being the elevation (35 m); θ: 45° (Fig. 2) (the reason behind considering angle as 45° comes from the previous experience on single BLEVE event. Since the real event was so complex to analyze that the parameters for each explosion, fireball and fragments were overlapped on many occasions. The whole bottles were thrown 30–35 m vertically due to the impulse generated by the overlapped explosions. Hence, the fragmentation of individual bottles were considered similar to that of a single BLEVE.); in the dynamic pressure equation $p_{dyn} = 0.5\rho v^2$ gives an overpressure of 28 kPa and z^*~5 (Fig. 4)). The above estimation also agrees with the fact that eyewitnesses stood 15–25 m from the explosion center and that sitting inside a car both of them did not suffer from any injury while recording the event. Please see Figs. 2–4.

In order to predict the explosion overpressure from available models following equations are utilized.

$$W_{\mathrm{TNT}} = \frac{0.021PV^*}{\gamma - 1} \cdot \left(1 - \left(\frac{P_a}{P}\right)^{\frac{\gamma-1}{\gamma}}\right) \quad (1)$$

where W_{TNT}: equivalent mass of TNT (kg); P: Pressure in the vessel just before the explosion: 19 bar (assumed); P_a: Atmospheric pressure: 1 bar; V^*: Volume of vapor inside the vessel plus the volume of vapor generated in the explosion; γ: ratio of specific heats: 1.4 (−).The V^* is given by

$$V^* = V + V_1 \cdot f \cdot \left(\frac{\rho_l}{\rho_v}\right) \quad (2)$$

V is the volume of vapor inside the vessel before the explosion

Table 1
Observed and model predicted characteristics of BLEVE and fireballs.

	Safe overpres. distance 5 kPa (m)	Fireball diameter (m)	Fireball elevation (m)	Burn time (s)	SEP (kW/m^2)	Thermal distance $\triangle y$ (1.5 kW/m^2 (m))	Missile X_{eq} (m)
Observed							
Maximum	37[a]	22	11	2	334[b]	400[c]	70
Minimum	15	16	9	1	169[b]	85[c]	15
Predictions							
1 cyl[d] (23 kg)	10	17	13	1.2	248	90	253
36 cyl (828 kg)	50	54	41	4	256	275	826
Equivalent (55 kg)	20	22	17	1.6	250	225	331

[a] Estimated by taking into velocity of fragments (31 m/s and 20 m/s).
[b] Estimated by max, and min. flame temperature (1600 K and 1350 K).
[c] Estimated by assuming transmissivity of 1 and view factors same as for scenarios of 2 cylinders and 36 cylinders.
[d] An average size of considered propane bottle (total weight = 57 kg, gas weight = 23 kg, length = 0.91 m, width = 0.32 m) (http://www.boconline.co.u).