Fire and Explosion Risks

IOSH visit 9th November 2016

Graham Atkinson
Agenda

- Fire resistant clothing
- Explosions in containers
- Storage fires
- Vapour cloud explosions
Agenda

Risks to:

- Individuals
  - Fire resistant clothing
  - Explosions in containers
  - Storage fires
  - Vapour cloud explosions
- Groups of workers
- Communities
Fire resistant overalls
Vapour explosions in containers

Fatalities are almost always caused by:

1. Fragments from weak containers

2. Ejection of burning liquid during explosions
A recent incident – 5 fatalities

Explosion in an IBC and a large external fire ball

- Vapour ignited – flashes back to IBC
- Internal explosion drives burning liquid out of the spout
A recent incident – 4 fatalities

Explosion in a tank – Failure of the bottom weld - Large external fire ball
Explosion in a mixer drives burning liquid out of a funnel
Fuel rich mixture in the mixer top
Flammable mixture in the mixer top
Flammable mixture in the mixer top – liquid ejected because of funnel
Fire Hazards of IBCs
Easily ignited accidentally or deliberately
How did IBCs get onto the market?

International IBC Fire Test Project (1995)

Sponsor: National Fire Protection Research Foundation
Test Organisation: Underwriters Laboratory

“Tests on water filled IBCs showed that massive releases of liquid are a rare occurrence. Most breaches produce small liquid release rates.”
Plastic IBC containing 800 litres diesel

(flashpoint 72 °C)
Aztec Chemicals
Grosvenor Chemicals
Mixing IBCs and drums makes fire-fighting particularly difficult
Vapour Cloud Explosions

Often the most serious incident that can occur at a site – affecting most people

Gasoline overfill
Gasoline spray
Gasoline overfill
LPG leak

Buncefield (2005)
Jaipur (2009)
12 fatalities
5 off-site
Puerto Rico (2009)
Amuay (2012)
60 fatalities
All off-site
Ufa (Urals) 1989  LPG pipeline failure

>600 fatalities in two trains passing through the vapour cloud
## VCE incidents reviewed

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brenham, TX</td>
<td>LPG Storage</td>
</tr>
<tr>
<td>Newark, NJ</td>
<td>Gasoline storage</td>
</tr>
<tr>
<td>Big Spring, TX</td>
<td>Refinery (LPG)</td>
</tr>
<tr>
<td>San Juan, Puerto Rico</td>
<td>Gasoline storage</td>
</tr>
<tr>
<td>Skikda, Algeria</td>
<td>LNG facility</td>
</tr>
<tr>
<td>Buncefield, UK</td>
<td>Gasoline storage</td>
</tr>
<tr>
<td>Amuay, Venezuela</td>
<td>Refinery LPG storage</td>
</tr>
<tr>
<td>Jaipur</td>
<td>Gasoline storage</td>
</tr>
<tr>
<td>Austin, TX</td>
<td>LPG pipeline</td>
</tr>
<tr>
<td>North Blenheim, NY</td>
<td>LPG pipeline</td>
</tr>
<tr>
<td>Donnellson, IA</td>
<td>LPG pipeline</td>
</tr>
<tr>
<td>Ruff Creek, PA</td>
<td>LPG pipeline</td>
</tr>
<tr>
<td>Port Hudson, MO</td>
<td>LPG pipeline</td>
</tr>
<tr>
<td>St Herblain, France</td>
<td>Gasoline storage</td>
</tr>
<tr>
<td>Geismar, LA</td>
<td>Petrochemicals</td>
</tr>
<tr>
<td>Naples, Italy</td>
<td>Gasoline storage</td>
</tr>
<tr>
<td>La Mede, France</td>
<td>Refinery (LPG)</td>
</tr>
<tr>
<td>Baton Rouge, LA</td>
<td>Refinery (LPG)</td>
</tr>
<tr>
<td>Norco, LA</td>
<td>Refinery (LPG)</td>
</tr>
<tr>
<td>Pasadena, CA</td>
<td>HDPE</td>
</tr>
<tr>
<td>Flixborough, UK</td>
<td>Petrochemicals</td>
</tr>
<tr>
<td>Devers, TX</td>
<td>LPG Pipeline</td>
</tr>
<tr>
<td>Lively, TX</td>
<td>LPG Pipeline</td>
</tr>
<tr>
<td>Ufa, USSR</td>
<td>LPG Pipeline</td>
</tr>
</tbody>
</table>
Vapour cloud development

Background

For 40+ years we have calculated cloud shapes in 2m/s and 5m/s wind speeds conditions to represent what happens to vapour in light winds and normal conditions.

2 m/s is the worst case but only occurs around 10-15 % of the time.

5 m/s gives more rapid dilution and occurs very often

Shape of the flammable cloud
We could find no real examples of the down wind tear-drop shaped clouds predicted by models used for risk assessment.

But it was very easy to find examples of vapour clouds that spread in all directions around the source...
Vapour cloud development

5 examples of cloud development in nil-wind conditions

Modelling of dispersion in a 2 m/s wind (Pasquill Stability Class F)
Average vapour cloud radius

Jaipur 400m
San Juan 400m
Buncefield 220m
Amuay 600m
Donnellson 350m
Calculated plume Amuay F2 weather
Data on dispersion conditions from...

Meteorological data

- Brenham, Texas (7:00am)
- San Jan, Puerto Rico (00:23 am)
- Big Spring, Texas
- Newark, New Jersey (0:10 am)

Vapor cloud structure

San Juan, Puerto Rico
<table>
<thead>
<tr>
<th>Incidents that occurred in nil/low–wind conditions</th>
<th>Vapor release rate (kg/s)</th>
<th>Duration prior to ignition (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brenham, TX</td>
<td>100</td>
<td>3600</td>
</tr>
<tr>
<td>Newark, NJ</td>
<td>35</td>
<td>&gt;900</td>
</tr>
<tr>
<td>Big Spring, TX</td>
<td>not known</td>
<td>not known</td>
</tr>
<tr>
<td>San Juan, Puerto Rico</td>
<td>50</td>
<td>1560</td>
</tr>
<tr>
<td>Skikda, Algeria</td>
<td>~10</td>
<td>&lt;300s</td>
</tr>
<tr>
<td>Buncefield, UK</td>
<td>19</td>
<td>1380</td>
</tr>
<tr>
<td>Amuay, Venezuela</td>
<td>13</td>
<td>&gt;5000</td>
</tr>
<tr>
<td>Jaipur</td>
<td>34</td>
<td>4500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incidents that probably occurred in nil/low-wind conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>St Herblain, France</td>
</tr>
<tr>
<td>Geismer, LA</td>
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<tr>
<td>Naples, Italy</td>
</tr>
<tr>
<td>La Mede, France</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incidents that occurred in light or moderate winds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baton Rouge, LA</td>
</tr>
<tr>
<td>Norco, LA</td>
</tr>
<tr>
<td>Pasadena, CA</td>
</tr>
<tr>
<td>Flixborough, UK</td>
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</tbody>
</table>
The data showed that incidents studied divided into two types:

1. Sustained releases in nil wind conditions
   - Rate: <100 kg/s
   - Duration: usually >1000 seconds

2. Large releases in windy conditions
   - Rate: >200 kg/s
   - Duration: usually <100 seconds
How do vapour clouds develop in nil-wind conditions?

The cloud formed in very low wind conditions (typically <1.3 m/s) normally has an area several hundreds of times larger than the same source in a 2 m/s wind.
Typical results for a 2” propane release (50 tonnes)

Release rate 32 kg/s
Ignition source density 0.01 acre$^{-1}$

<table>
<thead>
<tr>
<th>Weather</th>
<th>Area of flammable cloud (acres)</th>
<th>Ignition probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windy (F2 or D5)</td>
<td>0.1 to 1</td>
<td>0.1% to 1%</td>
</tr>
<tr>
<td>Nil wind</td>
<td>150</td>
<td>~70%</td>
</tr>
</tbody>
</table>

F2 conditions are roughly twice as likely as nil-wind but the chances of ignition are about 100 times less.

D5 conditions are roughly ten times more likely than nil-wind but the chances of ignition are 200 - 500 times less.

This illustrates why nil-wind incidents dominate VCE records for small vapour sources.
Explosion severity

What happens in a severe vapor cloud explosion?

Multimedia packages have been developed to present images from the incidents at:

- Buncefield
- Jaipur
- Flixborough
- San Juan
Part of the San Juan package
Part of the Jaipur package
Part of the Buncefield package
Part of the Flixborough package
What happens in a severe vapour cloud explosion?

This question has a surprisingly simple answer....

For bomb blast damage varies continuously with distance from the device.

For a low-lying nil-wind vapor cloud explosion the extent of blast damage is similar across all of the area covered by the cloud...

And similar for different clouds.
Cars

Buncefield

Amuay

Jaipur

Test explosion (1 bar)
Empty tanks
Full tanks
(Efficiently set on fire in the area covered by the vapor cloud)

San Juan  Buncefield  Amuay  Jaipur
Drums

Jaipur

Test (2 bar)

Buncefield

Test (2 bar)
Buildings

Buncefield

Jaipur

Amuay
**Part 2: Findings on explosion severity**

<table>
<thead>
<tr>
<th>Very large gasoline clouds that burned with a severe explosion (vehicles and drums crushed)</th>
<th>Very large gasoline clouds that burned as a flash fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buncefield</td>
<td>None found</td>
</tr>
<tr>
<td>Jaipur</td>
<td></td>
</tr>
<tr>
<td>Newark, NJ</td>
<td></td>
</tr>
<tr>
<td>San Juan</td>
<td></td>
</tr>
<tr>
<td>Naples</td>
<td></td>
</tr>
<tr>
<td>Saint Herblain</td>
<td></td>
</tr>
</tbody>
</table>

Gasoline clouds are particularly uniform in their effects because overfills and sprays tend to produce large clouds with concentrations towards the middle of the flammable range - concentrations over the UFL are not likely.
Explosion severity

<table>
<thead>
<tr>
<th>Very large LPG clouds that burned with a severe explosion (vehicles and drums crushed)</th>
<th>Very large LPG clouds that burned as a flash fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amuay</td>
<td>Donnellson, Iowa (pipeline)</td>
</tr>
<tr>
<td>Brenham</td>
<td></td>
</tr>
<tr>
<td>Port Hudson (pipeline)</td>
<td></td>
</tr>
<tr>
<td>La Mede</td>
<td></td>
</tr>
<tr>
<td>Skikda</td>
<td></td>
</tr>
</tbody>
</table>

What is the significance of the flash fire at Donnellson?

Is this an example of a very large, pre-mixed LPG cloud that burned as a flash fire – without transition to a severe explosion?
## Explosion severity

It is possible that the cloud at Donnellson was over the UFL (see below).

Flame would have spread over the top surface of the cloud before burning slowly down through the rich layer below.

<table>
<thead>
<tr>
<th></th>
<th>Mass release (tonnes)</th>
<th>Area of cloud (m²)</th>
<th>Mass/unit area (g/m²)</th>
<th>Equivalence ratio (assuming average height 2m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buncefield</td>
<td>26</td>
<td>150,000</td>
<td>173</td>
<td>1.1</td>
</tr>
<tr>
<td>San Juan</td>
<td>78</td>
<td>450,000</td>
<td>170</td>
<td>1.1</td>
</tr>
<tr>
<td>Donnellson</td>
<td>~150</td>
<td>300,000</td>
<td>500</td>
<td>3.3 (&gt;UFL)</td>
</tr>
</tbody>
</table>
Conclusion

If a very large cloud forms (at a concentration well within the flammable range) it is likely that there will be a severe explosion.

Currently this would be an appropriate basis on which to base risk assessment.
What kind of severe explosions occurred and what caused transition from a flash fire?

Detonations

Overpressure: 15-20 bar

Examples: Flixborough, La Mede (?)

Transition caused by flame propagation in highly confined and congested plant areas.

Severe explosion extends across the whole cloud - from the point of transition.
Detonations produce continuously curved steel posts and tubes.
Severe (episodic) deflagrations
Overpressure 2-5 bar

Examples: San Juan, Buncefield, Jaipur etc.

Transition triggered by buildings, pipe racks, vegetation, drains...

Severe explosion extends across the whole cloud - from the point of transition.
Severe deflagrations do not leave continuously curved posts
Case History – San Juan 23rd October 2009
Drain explosion

Extent of vapor cloud

Overfilled tank

Ignition

Drain explosion (failed manholes)

Key features
CCTV views allowed progress of the flame to be monitored.

Camera 1

Camera 2
For the first 3 - 4 seconds the images are blurred and overexposed.
After around 3 seconds flame propagated violently down a drain (near the edge of the cloud) but did not trigger transition to a fast flame.
Drain explosion in progress
For around 8 seconds the flame spread steadily across the site covering about 250 m (~30 m/s).
Then there was transition to a violent explosion

Transition to high pressure explosion
A sequence of violent explosions followed – crossing the open area around the overfilled tank (where the cloud was deepest)

The explosion covered about 140 m in 700 ms - corresponding to a sub-sonic rate of advance (200 m/s).

But individual episodes of violent combustion produced high overpressures
The locations of some explosion episodes can be pinpointed by triangulating from the two camera views.
Transition occurred in an area where there were intersecting pipe racks.
Alternative views of the transition area
The transition area does not include the kind of dense semi-confined pipework normally associated with transition to a severe explosion (DDT).

Plant areas like this will be found on most chemical sites – including LNG export sites.

This goes some way to explaining why transition has occurred so frequently for very large flammable clouds.
Summary

1. Nil-wind scenarios dominate risk for releases under 50 kg/s and contribute significantly to the risk for release rates up to about 250 kg/s.

2. For clouds that accumulate in nil-wind conditions the fuel concentration hardly changes from close to the source to the outer edge.

3. Vapor clouds that have accumulated from sustained small leaks have caused major incidents with cloud spread, blast damage and multiple fatalities up to >700m from source.

4. If a very large, homogenous cloud accumulates (and the concentration is somewhere near an equivalence ratio of 1) then transition to a severe explosion is likely for gasoline or LPG.