This is an author produced version of *The influence of obstacle separation distance on explosion severity. Is our design database conservative enough?*. 

White Rose Research Online URL for this paper: 
http://eprints.whiterose.ac.uk/110262/

**Conference or Workshop Item:** 
The influence of obstacle separation distance on explosion severity. Is our design database conservative enough?

Energy Research Institute
University of Leeds, UK
Turbulent explosion enhancement as a gas dynamic feed-back loop

Much work has been done with multi-obstacles investigating this mechanism to understand:

- increased explosion severity in congested areas
- transition to detonation

Limited work on the effect of **obstacle separation distance**
Cold flow turbulence

Baines and Peterson (1951)

\[(u'/U)_{\text{max}} = 0.225 K^{0.5}\]

Phylaktou & Andrews (1994)
Position of maximum cold flow turbulence

![Graph showing the relationship between obstacle blockage ratio (BR) and distance to maximum turbulence intensity (x/b)max.](image)

- Baines and Peterson (1951) - BL
- Baines and Peterson (1951) - PP
- Checkel (1981) - PP
- Groth and Johansson (1988) - SM
- DeOtte et al (1991) - PP
- Zhou and Lee (2004) - PP

Distance to max. turbulence intensity (x/b)_{max} (\text{m})

Obstacle blockage ratio, BR (\text{--})

t/d < 0.6
Explosion & Detonation studies with variable obstacle spacing

Obstacle separation distance, x/b

Obstacle blockage, BR (-)

Position of maximum cold flow turbulence
Objectives

To systematically vary the obstacle separation distance in gas explosions in order to

- identify the worst case interaction distance and

- relate this to the cold flow turbulence generation and decay profile.

- Relate findings to other explosion studies and explosion safety
Experimental – test rig

162 mm i.d., 8×0.5m + 1×0.25m sections, \( V_t = 0.092 \text{m}^3 \)

\[ V_d = 50 \text{ m}^3 \]
Experimental – obstacles

Hole grid plates

Flat bars
Results – General - Pressure

CH$_4$ 10% by vol.
0.3 BR obstacle
Single-hole

Double obstacle
1.75 m apart

Overpressure, $P$ (bar)

Single obstacle at 17D

2nd obstacle at 17D

1st obstacle at 6.2D

No obstacle

Time (ms)
Results – General – Flame speed

CH₄ 10% by vol.
0.3 BR obstacle
Single-hole

Double obstacle
1.75 m apart

Flame speed, $S_r$ (m/s)

1st obstacle

2nd obstacle

Single obstacle

No obstacle

Flame position, $x_{ig}/D$ (−)
Flame speed generated pressure

CH$_4$ 10% by vol.
Double obstacle
1.75 m apart
0.3 BR, 1-hole

Overpressure based on measured flame speed using

\[ P = \frac{2 \gamma M^2}{1 + M} \]

PT6 (end of the tube)

PT1 (ignition point)
Pressure development with separation distance

CH$_4$ 10% by vol.
Double obstacle
0.3 BR, 1-hole

Overpressure, $P$ (bar)

Time (ms)

$1^\text{st}$ obstacle
6.2D from spark

$x_s = 0.5$ m

$x_s = 1$ m

$x_s = 1.25$ m

$x_s = 1.75$ m

$x_s = 2.25$ m

$x_s = 2.75$ m
Maximum overpressure and flame speed as a function of dimensionless separation distance

CH₄ 10% by vol.
Double obstacle
0.3 BR, 1-hole

Experimental

Predicted from Eq. 5.1
Comparison with Cold Flow Turbulence

- Baines & Peterson
  - u'/U for 44% BR Grid plate

- Present data
  - Max. P as a function of obstacle separation distance

- CH4 10% by vol Double obstacle 30% BR Single hole

- Baines & Peterson
  - u'/U for 22% BR Grid plate

- Dimensionless distance, x/b

- Maximum Overpressure (bar)
Effect of blockage ratio

Intensity of turbulence, \( \frac{u'}{U} \) vs. Dimensionless distance, \( \frac{x}{b} \)

- 44% BR grid plate
  - Baines and Peterson (1951)

- 22% BR grid plate
  - Baines and Peterson (1951)

- 0.4 BR

- 0.3 BR

- 0.2 BR

Maximum overpressure, \( P_{\text{max}} \) (bar)

CH\(_4\) 10% by vol.
1-hole obstacles
Optimum separation distance compared to position of maximum cold flow turbulence
CH$_4$ 10% by vol.
1-hole obstacles

Moen et al. (1982)
Five orifice plates spaced at 2 m
50 m$^3$ tube

Present work
Two orifice plates spaced at $x_{\text{max}}$

Maximum overpressure, $P_{\text{max}}$ (bar)

Obstacle blockage ratio, BR (-)
Effect of obstacle scale, (flat-bars)

- 4-bar
- 2-bar
- 1-bar

Overpressure (bar)

Obstacle separation distance (m)

Double obstacle
20% BR
10% CH4 by vol
Baines and Peterson (1951)
22% BR

CH4 10% by vol.
Double obstacle, 0.2 BR

Intensity of turbulence, $u'/U$ (-)

Dimensionless distance, $x/b$ (-)

Maximum overpressure, $P_{max}$ (bar)
Obstacle separation distance, $x/b$

Position of maximum cold flow turbulence

1-D explosions worst case obstacle spacing separation
Harrison & Eyre (1987)
Conclusions

Importance of the obstacle separation distance in a simple double obstacle configuration clearly demonstrated.

- Profile of influence of separation distance consistent with cold flow turbulence profile
  - Position of maximum effect shifted further downstream in the explosion tests approximately by a factor of 3. This may be dependent on freedom of expansion directions
- Characteristic obstacle scale shown to be an appropriate scaling parameter.
- In practical applications the worst case separation distance needs to be avoided and in designing suitable experiments the worst case has to be incorporated.
- The results would suggest that in many previous studies of repeated obstacles the separation distance investigated may not have included the worst case set up, and therefore existing explosion protection guidelines may not account for worst case scenarios.
- Findings also have application in the critical separation distance between congested areas.
<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Conc.(v/v)</th>
<th>$\phi$</th>
<th>$S_L$</th>
<th>$E$</th>
<th>$Le$</th>
<th>$Ma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>10</td>
<td>1.06</td>
<td>0.45</td>
<td>7.49</td>
<td>1.0</td>
<td>3.5</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>7</td>
<td>0.72</td>
<td>0.24</td>
<td>6.26</td>
<td>1.0</td>
<td>-0.2</td>
</tr>
<tr>
<td>C$_3$H$_8$</td>
<td>4.5</td>
<td>1.12</td>
<td>0.53</td>
<td>8.10</td>
<td>0.8</td>
<td>2.6</td>
</tr>
<tr>
<td>C$_3$H$_8$</td>
<td>3</td>
<td>0.74</td>
<td>0.25</td>
<td>6.37</td>
<td>1.8</td>
<td>6.0</td>
</tr>
<tr>
<td>C$_2$H$_4$</td>
<td>4.3</td>
<td>0.65</td>
<td>0.30</td>
<td>5.82</td>
<td>1.3</td>
<td>3.0</td>
</tr>
<tr>
<td>H$_2$</td>
<td>18</td>
<td>0.52</td>
<td>0.97</td>
<td>5.09</td>
<td>0.5</td>
<td>-0.8</td>
</tr>
<tr>
<td>H$_2$</td>
<td>15</td>
<td>0.42</td>
<td>0.41</td>
<td>4.65</td>
<td>0.7</td>
<td>-1.2</td>
</tr>
</tbody>
</table>