Vented explosion of H₂/air mixtures: influence of vent cover
Vented explosions

- Explosion vents are commonly used to protect both internal equipment and the enclosure itself:
  - pressure leaves the closed domain => the internal overpressure < adiabatic limit
  - inflammable mixture partly leave the enclosure => to reduce the explosion mass

- Vented explosions are studied experimentally and numerically and analytically

- In complicated cases it is very difficult to find a proper analytical model:
  - presence of multiple vents
  - obstacles
  - stratification
  - vent covers

**Objective**: understand the influence of stratified clouds and vent cover inertia on the internal overpressure via experimental data and numerical simulations for vented explosion
Contents

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1 Experimental facility and numerical set-up
Experimental set-up:
- combustion cubic chamber of 1 m$^3$
- square vents of 0.01 m$^2$ (10 x 10 cm) and 0.25 m$^2$ (50 x 50 cm)
- BackWall ignition for vent cover and BackTop ignition for stratified mixtures
- 9 high speed pressure sensors (inside and outside)
- overpressure signals are post processed with low pass filter of 400 Hz
Numerical simulations

Simulations:
- FLACS v10.5 is used
- computational domain is chosen to be approximately the same size as in the experimental facility (8.3 m x 5.55 m x 3.4 m)
- the cell size is 2.5 cm (compared with grid of 5 cm)
- no initial turbulence
- measured concentration profiles are used
- Vyazmina et al.\(^1\) demonstrated that CFD is hardly applicable for small vent areas ➞ for benchmark only vent of 0.25 m\(^2\) is used

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Results for stratification and vent cover
Stratification

<table>
<thead>
<tr>
<th>Stratification</th>
<th>max %H₂</th>
<th>Experiment (mbarg)</th>
<th>Simulations (mbarg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-Layer</td>
<td>15%</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>94</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>212</td>
<td>390</td>
</tr>
<tr>
<td>S-Layer</td>
<td>15%</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>33-34</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>77</td>
<td>127</td>
</tr>
</tbody>
</table>

Simulations vs experiments:
- Simulation results are always conservative
  - for low reactivity (L-layers 15% and S-layers 15%) simulations are in better agreement with exp giving overestimation by ~20%
  - simulations overestimate the overpressure by ~50% for 20% H₂/air mixture
  - overestimation by a factor close to 2 for 25% H₂/air mixture
- For higher mixture reactivity a small error in the concentration strongly affects the obtained overpressure
- Simulations conservative => can be regarded as acceptable for gradient mixtures
Equivalent concentration: experiments

**Uniform vs non-uniform:**

- For the same amount of H\(_2\) (average 10\%):
  - the maximum pressure for non-uniform (17-4\%H\(_2\)) and (15-4\%H\(_2\)) is **6 (!) times higher** than for uniform 10\%H\(_2\) mixture
  - the flame velocity is **several times** faster
- For the same amount of H\(_2\) (average 7\%):
  - the mixture 12-2\%H\(_2\) burns **2 faster** than the 10-5\%H\(_2\)
  - maximum overpressure for 12-2\%H\(_2\) is > **10 times (!) higher** than for uniform 7 \%H\(_2\)
- Max concentration at the top governs the combustion behavior (not the average concentration)
Equivalent concentration: modeling

<table>
<thead>
<tr>
<th></th>
<th>Real H₂ %</th>
<th>Average H₂ %</th>
<th>Equivalent H₂ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-Layer 15%</td>
<td>4.3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>S-Layer 20%</td>
<td>6.15</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>L-Layer 15%</td>
<td>7.6</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>L-Layer 20%</td>
<td>11.2</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

Uniform vs non-uniform:
- Gradient layers give higher overpressure than the average homogeneous mixture.
- The equivalent concentration is more than twice the average concentration.
Effect of vent cover: Exp vs Model

- The vent cover enhances the max overpressure inside the enclosure.
- The thicker the vent cover is, the higher max overpressure is inside the vessel.
- Huge negative pressure impulse (physical ??)

<table>
<thead>
<tr>
<th>$H_2$ %</th>
<th>Vent cover (mm)</th>
<th>Exp. (mbarg)</th>
<th>Model (mbarg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.3</td>
<td>no</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>12.2</td>
<td>no</td>
<td>33</td>
<td>34</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>38</td>
<td>42</td>
</tr>
</tbody>
</table>
3 Conclusions
Conclusion

● **General results from experiments**
  - Vented deflag. of a stratified H\textsubscript{2}/air mixture leads to much higher max overpressure compared to the uniform H\textsubscript{2}/air average concentration
  - The combustion is governed by the max. H\textsubscript{2}/air concentration (not by the average)
  - A vent cover leads to greater combustion pressure
  - Enormous negative pressure phase

● **For stratified mixtures, FLACS simulations are always conservative**
  - could be safely used in industrial situations

● **For vent covers, FLACS gives reasonable agreement**
Thank you for your attention!!!