EXPERIMENTAL MEASUREMENTS OF STRUCTURAL DISPLACEMENT DURING HYDROGEN VENTED DEFLAGRATIONS FOR FE MODEL VALIDATION

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Presentation overview:

- Small Scale Enclosure
- Experimental measurements
- FE model
- Comparison between data and FE model
- Conclusions
Small Scale Enclosure

Investigation of vented hydrogen explosions in installations such as gas cabinets, cylinder enclosures, dispensers and backup power systems.

Variables under investigation

- **Hydrogen concentration**: between 10%vol. and 18%vol.

- **Vent location**: on the top and on the upper front wall

- **Vent type**: plastic sheets in different configurations and three different types of FIKE explosion panel

- **Ignition location**: 0.5 m, 1 m and 1.5 m from the floor along the centreline of the enclosure

- **Internal congestion**: empty enclosure, 1 bottle and 3 bottles placed inside

Vents Area:
- Top vent: 3 Plastic sheets
- Front vent: 3 FIKE vents type

**Bottles dimensions:**
- volume 50 liters
- height 1.68 m
- diameter 0.23 m
Small Scale Enclosure

- Internal camera
- Concentration sampling location
- Igniters
- Fan

Experimental measurements of structural displacement during hydrogen vented deflagrations for FE model validation
Small Scale Enclosure – Pressure transducers

Kistler piezo resistive Transducers
Adquisition frequency: 5 kHz
Displacement measurements methods

**Antenna**
- Simplicity
- Poor accuracy
- No displacement-time histories recording

**Keyence Laser Sensor IL-S025**
- Displacement-time histories recording
- 5 kHz acquisition
- 1 μm repeatability
Displacement measurement test plates and positions

<table>
<thead>
<tr>
<th>Measurement method</th>
<th>Test plate</th>
<th>Plate thickness [mm]</th>
<th>Sensor location</th>
<th>TEST # (interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>Lower</td>
<td>2</td>
<td>Plate centre</td>
<td>TP1-TP20</td>
</tr>
<tr>
<td>Laser</td>
<td>Lower</td>
<td>5</td>
<td>Plate centre</td>
<td>TP21-TP29, TP65-TP70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>91.3 cm from floor</td>
<td>TP30-TP33</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>115.45 cm from floor</td>
<td>TP34-TP36, TP45-TP52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>5</td>
<td>Plate centre</td>
<td>TP37-TP44, TP53-TP64, TP71-TP76</td>
</tr>
</tbody>
</table>

Displacement measurements experimental matrix:
- 2 thicknesses used (2 mm and 5 mm)
- 4 sensor locations
Data Analysis - Mechanical measurement

Problems found after preliminary measurements:
- 2 mm thick plate undergoes plastic deformation at very low overpressures
- Plastic deformation affects the displacement measurements of the following tests

Solutions taken to provide more reliable data:
- **2 mm thick plate was substituted with 5 mm** thick plate which shows an elastic response to the applied internal pressure
- The displacement measurement was performed using a **laser sensor**
Data Analysis – Laser measurement

Tp22 - Test set up
- 13.04% vol.
- Top vent
- Plastic sheet 1
- Centre ignition
- 1 bottle inside

Displacement
Measurement method: laser
Test plate thickness: 5mm
Measurement location: Plate centre
Maximum displacement: 3.28 mm
Data Analysis – Laser measurement

The results are quite scattered along a theoretical straight line. Due to extremely dynamic nature of the deflagration the overpressure measured in the two locations (Pside, Pbottm) are not always representative of the overpressure applied to the lower front plate.

The laser was moved upward along the centerline to avoid sensor saturation at high overpressure.

Test plate thickness: 5 mm

- 115.45 cm
- 91.3 cm
- 69 cm (centre)
## Data analysis

<table>
<thead>
<tr>
<th>Test</th>
<th>TP27</th>
<th>Test</th>
<th>TP59</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstacle configuration</td>
<td>1 bottle</td>
<td>Obstacle configuration</td>
<td>1 bottle</td>
</tr>
<tr>
<td>Ignition location</td>
<td>Bottom Ignition (#2)</td>
<td>Ignition location</td>
<td>Bottom Ignition (#2)</td>
</tr>
<tr>
<td>Vent location</td>
<td>Top vent</td>
<td>Vent location</td>
<td>Top vent</td>
</tr>
<tr>
<td>Average H₂ concentration</td>
<td>15.97 % vol.</td>
<td>Average H₂ concentration</td>
<td>15.9 % vol.</td>
</tr>
<tr>
<td>Plate under investigation</td>
<td>Lower front plate</td>
<td>Plate under investigation</td>
<td>Upper front plate</td>
</tr>
<tr>
<td>Displacement measurement location</td>
<td>69 cm from the bottom (plate centre)</td>
<td>Displacement measurement location</td>
<td>31 cm from top (plate centre)</td>
</tr>
</tbody>
</table>

### Experimental measurements of structural displacement during hydrogen vented deflagrations for FE model validation

- **Test TP27**
  - Obstacle configuration: 1 bottle
  - Ignition location: Bottom Ignition (#2)
  - Vent location: Top vent
  - Average H₂ concentration: 15.97 % vol.
  - Plate under investigation: Lower front plate
  - Displacement measurement location: 69 cm from the bottom (plate centre)

- **Test TP59**
  - Obstacle configuration: 1 bottle
  - Ignition location: Bottom Ignition (#2)
  - Vent location: Top vent
  - Average H₂ concentration: 15.9 % vol.
  - Plate under investigation: Upper front plate
  - Displacement measurement location: 31 cm from top (plate centre)

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![Graph](image-url)  

**Maximum measured displacement [mm]**  

- TP59  
- TP27  

**Time [s]**  

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Data analysis

Taking the measurement on upper plate the difference between applied overpressure on the target plate and the recorded pressure at Pside is minimized. Pside transducer is just opposite of the displacement measurement location.

Experimental measurements of structural displacement during hydrogen vented deflagrations for FE model validation

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## Experimental measurements of structural displacement during hydrogen vented deflagrations for FE model validation

### Video

<table>
<thead>
<tr>
<th># Test</th>
<th>Avg. conc [%vol.]</th>
<th>Vent location</th>
<th>Vent type</th>
<th>Ignition location</th>
<th>Obstacle conf.</th>
<th>Test plate thick. [mm]</th>
<th>Laser location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP55</td>
<td>17.8</td>
<td>Top</td>
<td>Plastic sheet 1</td>
<td>Bottom</td>
<td>3 bottles</td>
<td>5</td>
<td>Upper plate centre</td>
</tr>
<tr>
<td>TP56</td>
<td>14</td>
<td>Top</td>
<td>FIKE 2</td>
<td>Bottom</td>
<td>3 bottles</td>
<td>5</td>
<td>Upper plate centre</td>
</tr>
<tr>
<td>TP66</td>
<td>15.8</td>
<td>Front</td>
<td>Plastic sheet 1</td>
<td>Centre</td>
<td>1 bottle</td>
<td>5</td>
<td>Lower plate centre</td>
</tr>
</tbody>
</table>
FE model

A finite element model representing the upper was developed by using IMPETUS Afea Solver.

Main elements of FE model:
- main side-wall test plate (5 mm)
- main rectangular frame consisting of 4 mm thick L-profiles with outer flange dimensions 50 mm (L50x4mm)
- 30 bolts with 10 mm OD
- 30 corresponding nuts
- 30 corresponding washers
- rear end of the main frame was constrained
FE Simulation set up

<table>
<thead>
<tr>
<th>Test Id</th>
<th>Average $\text{H}_2$ Conc.</th>
<th>Vent location</th>
<th>Vent type</th>
<th>Ignition location</th>
<th>Obstacle conf.</th>
<th>Test plate #</th>
<th>Test plate thick.</th>
<th>Displac. Measur. method</th>
<th>Displac. Measur. Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP37</td>
<td>14.1%</td>
<td>Top vent</td>
<td>FIKE Vent 3</td>
<td>Bottom</td>
<td>3 bottles</td>
<td>(2)</td>
<td>5 mm</td>
<td>Laser</td>
<td>Plate centre</td>
</tr>
</tbody>
</table>

The simulation was done in two steps:
- Step 1: bolts pre-loaded to an axial stress of 200 MPa (representing the 20 Nm pre-torque).
- Step 2: TP37 pressure-time curve was imported and used to load the complete rear surface of the test plate.
**FE Simulation results**

The displacement-time curve of the centre of the test plate was extracted and compared to experiment.

- Plot of the displacement field of the test plate at time \( t=0.102 \) s.
- Simulation vs experiment: Displacement-time curve
Pressure ramps were simulated by using a combination of $p_{\text{max}}$ and $t_{\text{end}}$ to characterize the smooth ramp up below

$p_{\text{max}}$ [100, 200, 300] [mbar]  
$t_{\text{end}}$ [0.02, 0.03, 0.04] [s]
Conclusions

Experimental measurements
- 5 mm thick plate is necessary to avoid metal plasticization that can affect the following measures;
- the measurement location has to be representative of pressure with respect to pressure transducer in order to ensure that the dynamic behavior of deflagration does not affect the results.

Validation of numerical model
The mesh density, element type and boundary conditions appears to represent this experimental test set-up well. (For larger pressure loads involving possible plasticity and material failure it would have been necessary to use more representative material models and possibly a finer mesh). Furthermore the pressure signal is not sampled directly at the location of the displacement measurement introducing an error whenever the dynamic of the deflagration causes spatial differences inside the enclosure.

The next planned experimental campaign that UNIPI, with help of IMPETUS and FIKE, will provide additional data useful to validate FE model in a bigger variety of conditions and to improve his predictive capacity.
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