THE ROLE OF THE FLOW FIELD GENERATED BY THE VENTING PROCESS ON THE PRESSURE TIME HISTORY OF A VENTED DEFLAGRATION

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Presentation overview:

• Experimental set-up (video recording)
• Perturbation originated by the two pivotal moments in vented deflagrations:
  - Vent opening
  - Flame front reaching the vent
Experimental set-up

Height – 2000 mm
Width – 920 mm
Depth – 620 mm

l = 50 mm
a = 4 mm

Vent dimensions
b = 500 mm
c = 800 mm
Experimental set-up

Pressure transducers:
- **Bottom**: Center of the floor
- **Side**: On the centerline of the back plate 1.5 m above the floor

- **External camera**
- **Internal camera**
- **Fan**
- **Hydrogen release hole**

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Experimental set-up

5 Sampling locations

Ignition location:

Bottom:
On the centerline 0.5m above the floor

Centre:
On the centerline 1m above the floor

Top:
On the centerline 1.5 m above the floor
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**Experimental set-up**

**Internal obstacle configuration**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Free Volume</th>
<th>Volume Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty SSE</td>
<td>~1.141 m³</td>
<td>4.86%</td>
</tr>
<tr>
<td>1 bottle</td>
<td>~1.085 m³</td>
<td>14.58%</td>
</tr>
<tr>
<td>3 bottles</td>
<td>~0.974 m³</td>
<td></td>
</tr>
</tbody>
</table>

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Experimental set-up

Vent locations

Top vent

Front vent

Vent type

Plastic sheets

FIKE vents

1

2

3

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Experimental set-up

Video recording

Video recording was performed at \textbf{240 fps} (frames per second)

Salt water spray injection system

Spray injection location

Visible Emission Spectra Sodium Chloride

External camera

Internal camera

Spray injection location
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**Experimental set-up**

**Video recording**: Synchronization with pressure/time history

\[ Tr + Ts = \frac{1}{240} \, s = 4.17 \times 10^{-3} \, s \]
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Experimental set-up

Video recording: Synchronization with pressure/time history

Video has been slowed down 10 times
Pivotal moments in vented deflagrations

Every vented deflagration involve two crucial moments:

- **Vent opening**
- **Flame reaches the vent**

Both of these pivotal moment modify the boundary condition in which the flame front is developing and trigger perturbations.

**Vent opening:**

- Introduces perturbations generated by the $dP$ at the vent surface which in turn originate a flow field directed towards the vent area
- Changes the distribution of the forces applied to the flame front by the expansion of the combustion products inside the «flame bubble»

**Flame front reaches the vent area:**

- Introduces perturbations generated by the sudden increase of the $dV/dt$ at the vent surface which in turn originates perturbations
- The generated combustion products are removed towards the vent area and do not contribute anymore to the acceleration of the flame front (flame tends to become “quasi-stationary”)
1. Introduces perturbations (accelerations) generated by the dP at the vent (The flame front is accelerated outwards by the expansion of the combustion products, so the effect of the superimposed “acoustic” accelerations is negligible)

2. Originate a flow field directed towards the vent area

3. Changes the distribution of the forces applied to the flame front by the expansion of the combustion products inside the «flame bubble»
Vent opening: Provokes changes in the distribution of the forces applied to the flame front by the expansion of the combustion products.

Test TP73 (18%vol)

Velocity of the flame front increasing
Flame front travels 0.5 to 0.6 m in 1 frame 12.5 $10^{-3}$ s
~40 m/s

Velocity of the flame front decreasing
Flame front reaching the vent area:

1. Introduces perturbations (accelerations) generated by the sudden change of $dV/dt$ at the vent (Such perturbation travel at the speed of sound)
   1. Helmholtz oscillations
   2. Acoustic response of the chamber

2. Combustion products generated inside the «flame bubble» direct mostly towards the vent area and do not contribute anymore to the acceleration of the flame front in outward direction (Flame front behaves like a free standing flame)
Flame front reaching the vent area: accelerations

The abrupt increase of the flow out of the vent area is responsible for the discontinuity that generates the acoustic response of the chamber:

1. Helmholtz oscillations
2. Acoustic response of the chamber

\[ \frac{dV}{dt} = C_d \cdot A_v \cdot (2\Delta P/\rho)^{1/2} \]

Distance traveled by perturbation (acceleration) 1.8 m
Time ≤ 1 frame = 1/240s = 4.17 x 10^{-3}s

\[ v_p \geq \frac{1.8m}{1/240} \geq 432 \frac{m}{s} \]

Compatible with a perturbation travelling with the speed of sound in the combustion products.

Test TP55: H₂ average conc. 17.8%
Flame front reaching the vent area: flow field affecting the flame front opposite the vent

Combustion products generated inside the «flame bubble» are sucked towards the vent area, the generated flow field drags the flame front towards the vent, the flame “survives” only in regions were the velocities are lower.
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Local pressure peaks: flow field around obstacles

Test TP55: $\text{H}_2$ average conc. 17.8%
3 bottles – Top vent

Test TP52: $\text{H}_2$ average conc. 17.7%
3 bottles – Front vent

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The role of the flow field generated by the venting process on the pressure time history of a vented deflagration

Local pressure peaks: damages

Broken welds
The role of the flow field generated by the venting process on the pressure time history of a vented deflagration

Local pressure peaks: damages

Camera protection case cap removed (broken hinges and closure – aluminum)

Displaced camera
The role of the flow field generated by the venting process on the pressure time history of a vented deflagration

Acoustic oscillations

Frames 601 517
Frames 605 521
Frames 609 525
Frames 613 529
Flame front reaching the vent area: (free standing flame behavior after venting)

Test TP74 (14.3% vol.)

Frames

609
525
409

Flame front before reaching the vent area

Progressive changes in the flame shape after the flame front reaches the vent area

Geometrical analogy with the experimental set-up of Searby (Acoustic instabilities in premixed flames - Comb. Science and Tech. 1992 Vol.81)

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Flame front reaching the vent area: (flame shape during last phase of deflagration)

Luminous emission from spontaneously curved flames in the absence of acoustic instabilities
“The flame typically has a curved shape with large “soft” cells generated by Darreius-Landau instabilities”
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The HySEA project received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) under grant agreement No. 671461. This Joint Undertaking received support from the European Union’s Horizon 2020 research and innovation programme and United Kingdom, Italy, Belgium and Norway.
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THANK YOU
For your attention