Hydrogen Bubble Dispersion and Surface Bursting Behaviour

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Why Study Hydrogen Bubbles?

(1) Sources

- $\text{H}_2$ is a concern for nuclear waste storage & decommissioning operations.
  - Hydrogen produced in liquids and sludges
    - Corrosion of metals particularly Mg
    - Radiolysis

- Release in form of bubbles
  - Small bubbles – often slow steady releases
  - Large volumes, 100’s L – disturbance of sludge beds or containers
Why study hydrogen bubbles?

(2) Concerns

- Hydrogen releases could form flammable atmospheres and be ignited.

- Typical Questions:
  - Extent of flammable region above surface
  - How quickly is it dispersed
  - Build up in roof space possible?

- Data useful for model development and validation
Visualising hydrogen in air

• Rapid, transient phenomenon
• Non-invasive measurement
• Simultaneously at different positions
• Schlieren photography
  – Available
  – Concentration gradient
  – Reasonable sensitivity - H₂-air mix from pipe visible at 4% H₂
Experimental apparatus

- Toughened glass tank
- Bubbles from
  - Various size submerged pipes
- Schlieren system
- Second camera
  - Bubble sizing (with retractable rod)
  - Rise time and speed
  - Filming bursting process
Section A-A

0.2 m diameter, 2 m focal length spherical mirror

knife edge cut off

glass walls (19mm thick, toughened)

slit and incandescent light source (via fibre optic cable)

high speed video camera (schlieren imaging)

high speed video camera (rising bubbles and bursting)

retractable rod for focusing

hydrogen supply

800mm

1500mm
2 cm³ H₂ bubble rising to a water surface
length of video clip  600 ms
Schlieren imaging of 2 cm$^3$ bubble burst
length of video clip 600 ms
Visible extent of plume

![Graph showing the relationship between bubble size and visual detection limit. The x-axis represents bubble size (cm$^3$) ranging from 0 to 2.5, and the y-axis represents visual detection limit (cm) ranging from 0 to 12. The data points form a positive trend line, indicating an increase in visual detection limit with increasing bubble size.](image)
Visible schliere and flammability

- Can visualise 4% H₂ but schliere depends on conc. Gradient

- Deliberate ignition bubble burst

- Modified, orthogonal apparatus

- Confirmed visible extent greater than ignitable extent

<table>
<thead>
<tr>
<th>Igniter Height, mm</th>
<th>Ignition Frequency</th>
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<tbody>
<tr>
<td>40</td>
<td>22/31</td>
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<tr>
<td>53</td>
<td>6/30</td>
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<tr>
<td>65</td>
<td>0/27</td>
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</tbody>
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2.5 cm³ bubble, visible extent ~ 10 cm
Bubble burst mechanism

- Experiments undertaken to visualise bursting in more detail.
- Same apparatus, but higher frame rates
- Gain better understanding of bursting process
  - Explore modelling approaches
  - Aerosol production
1.5 cm³ bubble – rear burst
length of video clip 12 ms

1.5 cm³ bubble – side burst
length of video clip 8 ms
Normal and schlieren video of same 1.5 cm$^3$ bubble
Discussion - Flammable extent of plume

- Ignition experiments indicate limit of visible schlieren bounds flammable extent
- Obtained data for visible schlieren limit vs bubble size
- Compared with Sellafield in-house model – buoyant expanding sphere
  - Visible limit ~ 50% model prediction
Discussion - Bubble bursting behaviour

• Burst mechanism:
  • Appearance of bubble
  • Nucleation of small tear/hole
  • Rapid retraction of film (a few ms) gives rim instability and formation of ligaments/droplets.
  • Some hydrogen is forced out of hole as bubble collapses, but much remains in place
  • Variation in nucleation site and initial amount of dispersion

• Modelling – OpenFOAM
  • Able to reproduce some of the behaviour but computationally very demanding
Conclusions

• Schlieren & deliberate ignition used to estimate extent of flammable plume

• Significant momentum imparted to hydrogen
  – Simple Sellafield models conservative

• Bubble bursting complex
  – Very fast ~3 ms, films peels back from initial hole, rim formation
  – Variation in nucleation site, time to collapse and initial dispersion
Further Investigations – Larger Releases

- New apparatus commissioned
- Lens and grid schlieren system
  - Visualise much larger area
    - Large diameter optics not required
    - But reduced sensitivity
- Used to visualises H₂ releases up to 22 litres in ~ 1m³ volume
source grid printed on acetate sheet over reflective material

water vessel

hydrogen bubble release mechanism

perspex cabinet

viewing screen (ground glass screen backed by Fresnel lens)

hydrogen in

Cut off grid (negative of source grid). Adjustable for x,y,z position and rotation

High quality field camera lens (Schneider Optics, Apo-Symmar 150/5.6)
14 Litre Hydrogen Release

time = 0.60 s
14 L Hydrogen Release

LSBU Experiment

CFD Simulation

time = 1.33 s
Thank You
For
Listening