The Mitigation of Hydrogen Explosions using Water Fog, Nitrogen Dilution and Chemical Additives

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Aim: Lower Explosion Overpressure

• Ignition of hydrogen in an enclosure
  – Explosion $\Rightarrow$ Overpressure
  – Prevent loss of structural integrity
• Achieve inerting – prevent ignition (ideal case)
• OR reduce burning velocity of deflagration
  – Allow venting longer time to relieve pressure build up in compartment
  – Reduce the total volume of hydrogen that burns
• How?
  – Water Mist Fog
  – Nitrogen Dilution
  – Chemical Additives
LSBU Research Work

- Explore mitigation of hydrogen explosions
  - Water mist fog
  - Nitrogen dilution
  - Sodium hydroxide

- LSBU experiments
  - Burning velocity rig
  - Cylindrical explosion vessel tests
Burning Velocity Inhibition Experiments

- Characterise burning velocity for $\text{H}_2$-$\text{O}_2$-$\text{N}_2$ mixtures
  - Equivalence ratio
  - Fog density
  - Oxygen index ($\text{O}_2/\text{O}_2+\text{N}_2$)
  - Sodium hydroxide
Schlieren Images of the $\text{H}_2$–Air Flame

H$_2$ Flame

H$_2$ Flame with Water Fog
The Effect of Fog Density upon Burning Velocity versus $\Phi$ for $\text{H}_2$-$\text{O}_2$-$\text{N}_2$ Flames

H$_2$-Air flame ($\Omega = 21\%$)  
Nitrogen diluted flame ($\Omega = 16\%$)
The Effect of NaOH Fog on the Burning Velocity of an H₂-Air Flame with Φ = 2

![Graph showing the effect of NaOH fog on the burning velocity of an H₂-Air flame with Φ = 2. The graph plots burning velocity (m/s) against mist concentration (mg/l). The data points indicate a decrease in burning velocity as the mist concentration increases. Two lines are plotted: one for water and one for 0.5M NaOH. The 0.5M NaOH line shows a steeper decrease in burning velocity compared to water.]
Overpressure Mitigation Experiments

• Determine rise in overpressure for H$_2$-O$_2$-N$_2$ mixtures in a cylindrical vessel
  - Equivalence ratio
  - Vent size
  - Fog density
  - Oxygen index
  - Sodium hydroxide
The LSBU Cylindrical Explosion Rig

- Pressure sensor
- Exploding wire igniter
- Hydrogen in
- Hydrogen/air vent
- Mixing fan
- Ultrasonic fogger unit
- Water
- 380 mm
- 270 mm
- 95 mm
- 60 mm
- 30 mm
- 450 mm
- 12.5 mm
- 800 mm
The Effect of Fog on the Explosion Overpressure for H₂-Air (Φ = 0.39) in the (nominally) Unvented Vessel
Effect of Fog Density on Explosion Overpressure-Time Histories

200 mm Diameter Vent

100 mm Diameter Vent
The Effect of Fog Density upon Flammability Limits determined for $\text{H}_2$-$\text{O}_2$-$\text{N}_2$ Mixtures

- Fog + Nitrogen dilution
- Fog + Nitrogen dilution + NaOH
Modelling Studies

- Simulate LSBU explosion tests
- Use empirical burning velocity data as input
- Explore mitigating effect of water fog & nitrogen dilution on overpressure
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Conclusions

• Characterised performance of water fog, nitrogen dilution and NaOH in mitigation of hydrogen deflagrations
• High density water fog (SMD 5 µm) can significantly reduce the burning velocity and rate of pressure rise
• Using NaOH additive with water fog
  – produces a sharp reduction in burning velocity above a critical fog density
  – Significantly narrows flammability limits
• Using Water Fog + N₂ + NaOH together provides optimal mitigation performance