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

P. Battersby, P. Holborn, J. Ingram,
A. Averill and P. Nolan
London South Bank University, UK
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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

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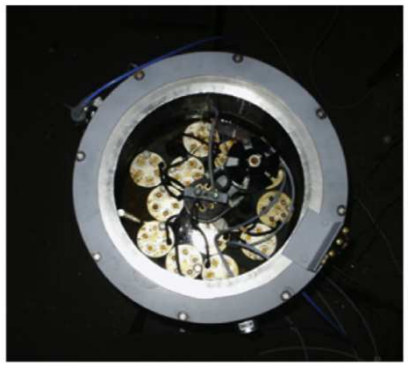
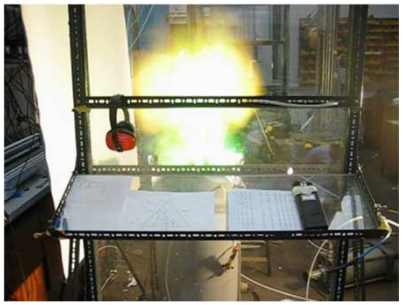
LSBU Research Work





- Explore mitigation of hydrogen explosions
  - Water mist fog
  - Nitrogen dilution
  - Sodium hydroxide
- LSBU experiments
  - Burning velocity rig
  - Cylindrical explosion vessel tests

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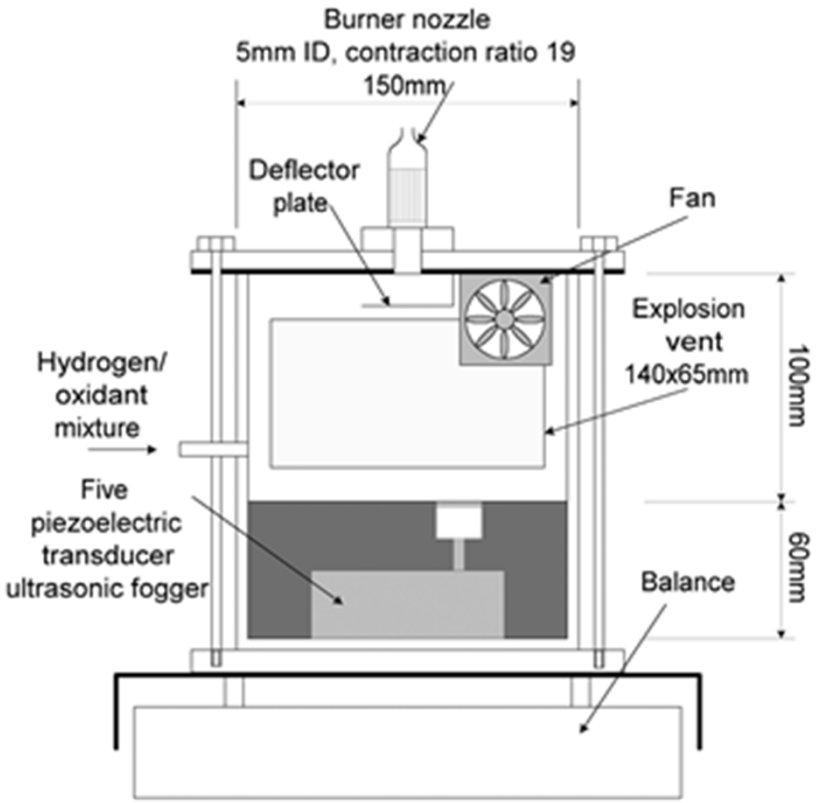
Burning Velocity Inhibition Experiments



- Characterise burning velocity for H_2-O_2-N_2 mixtures
  - Equivalence ratio
  - Fog density
  - Oxygen index (O_2/O_2+N_2)
  - Sodium hydroxide

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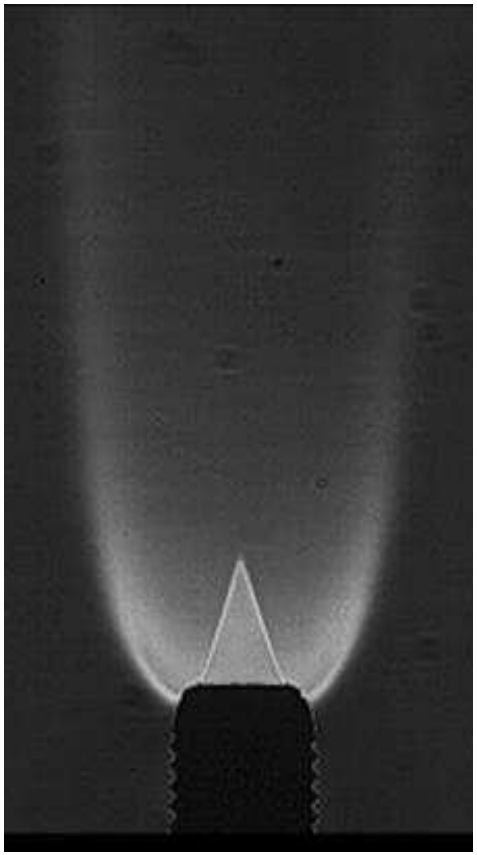
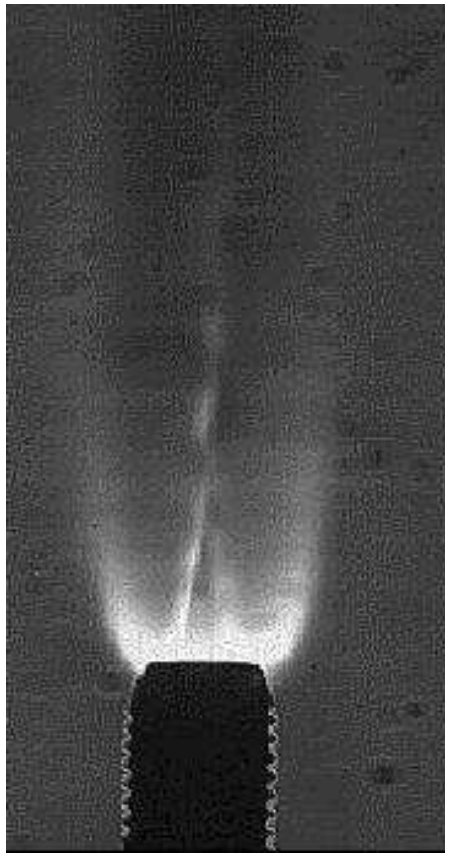
Schlieren Images of the H_2–Air Flame



H_2 Flame



H_2 Flame with Water Fog

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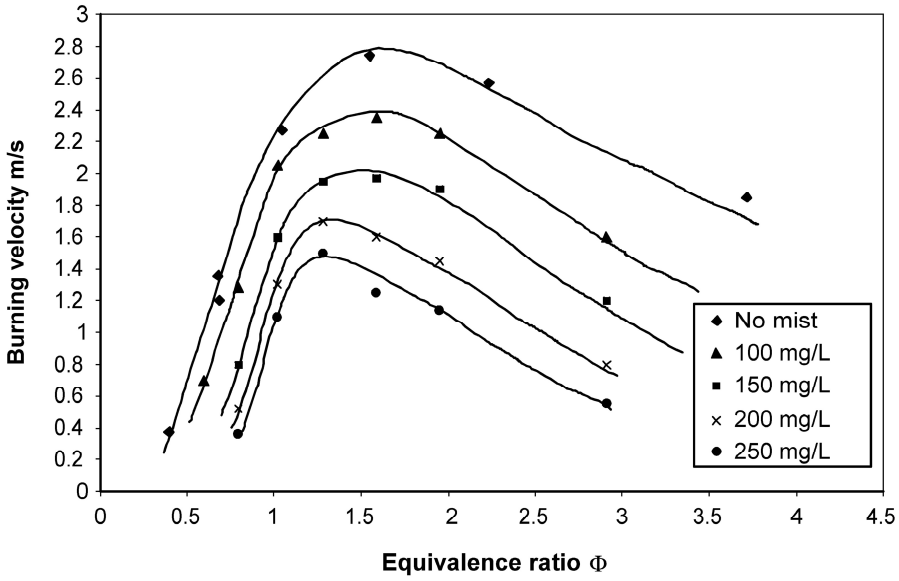
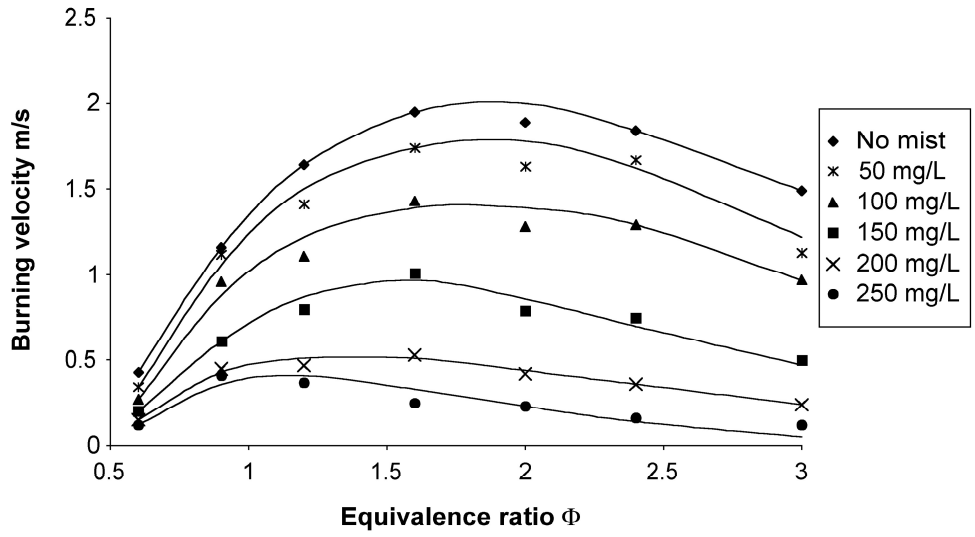
The Effect of Fog Density upon Burning Velocity versus Φ for H_2-O_2-N_2 Flames



H_2-Air flame (Ω = 21%)



Nitrogen diluted flame (Ω = 16%)

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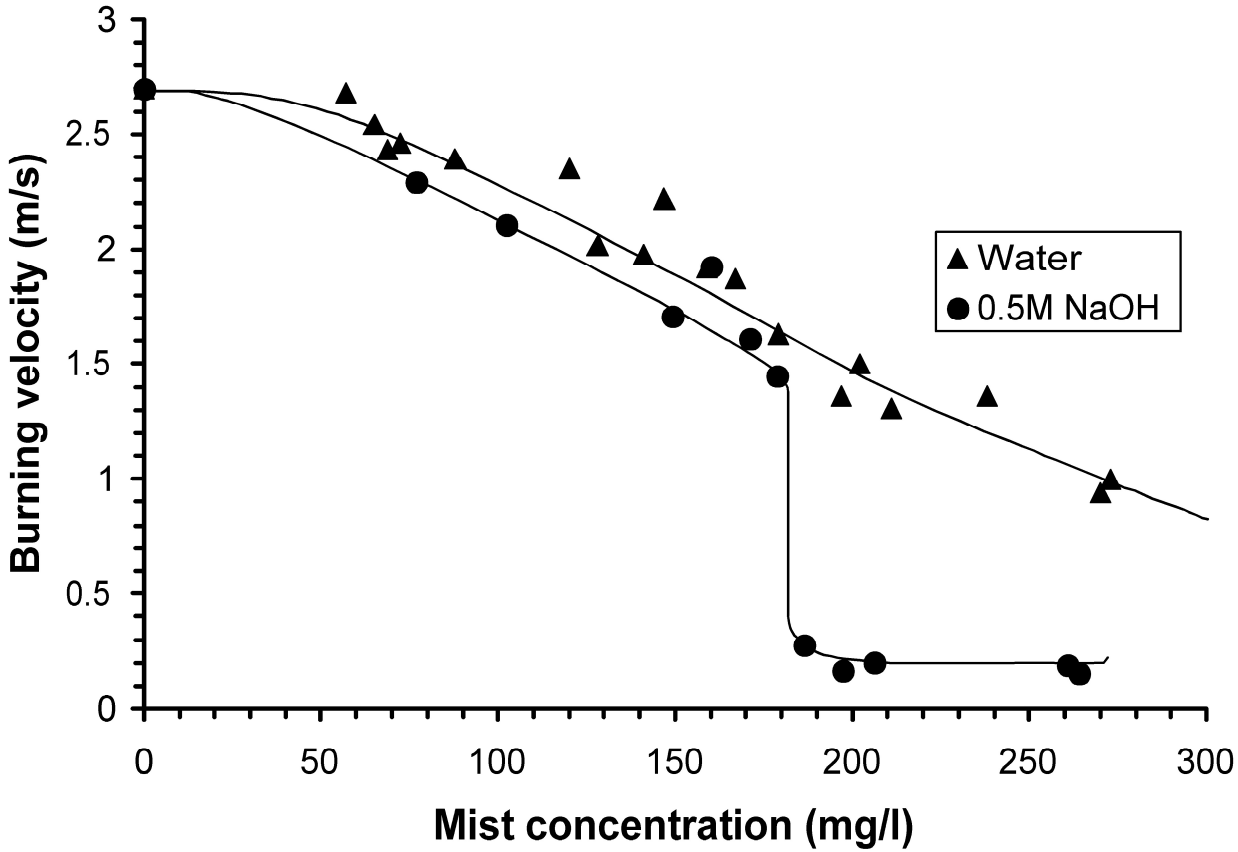
The Effect of NaOH Fog on the Burning Velocity of an H_2-Air Flame with $\Phi = 2$



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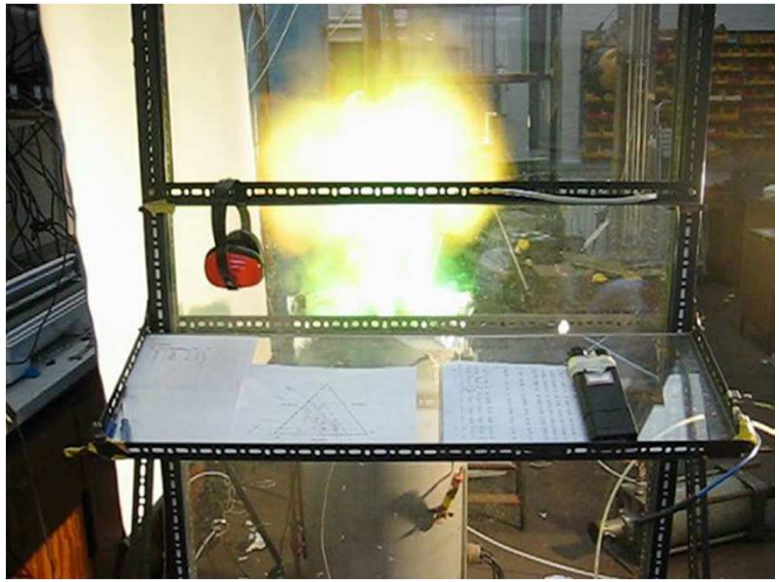
Overpressure Mitigation Experiments



- 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

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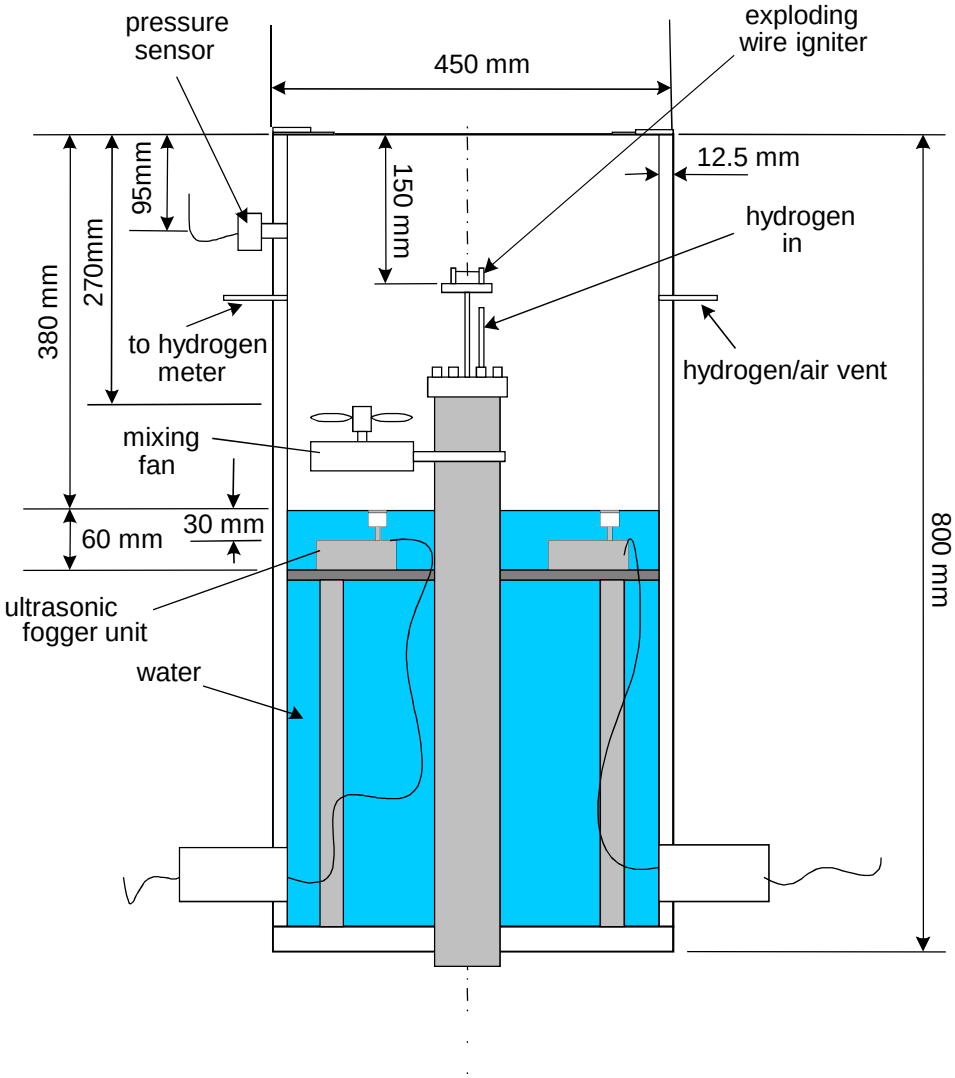
The LSBU Cylindrical Explosion Rig



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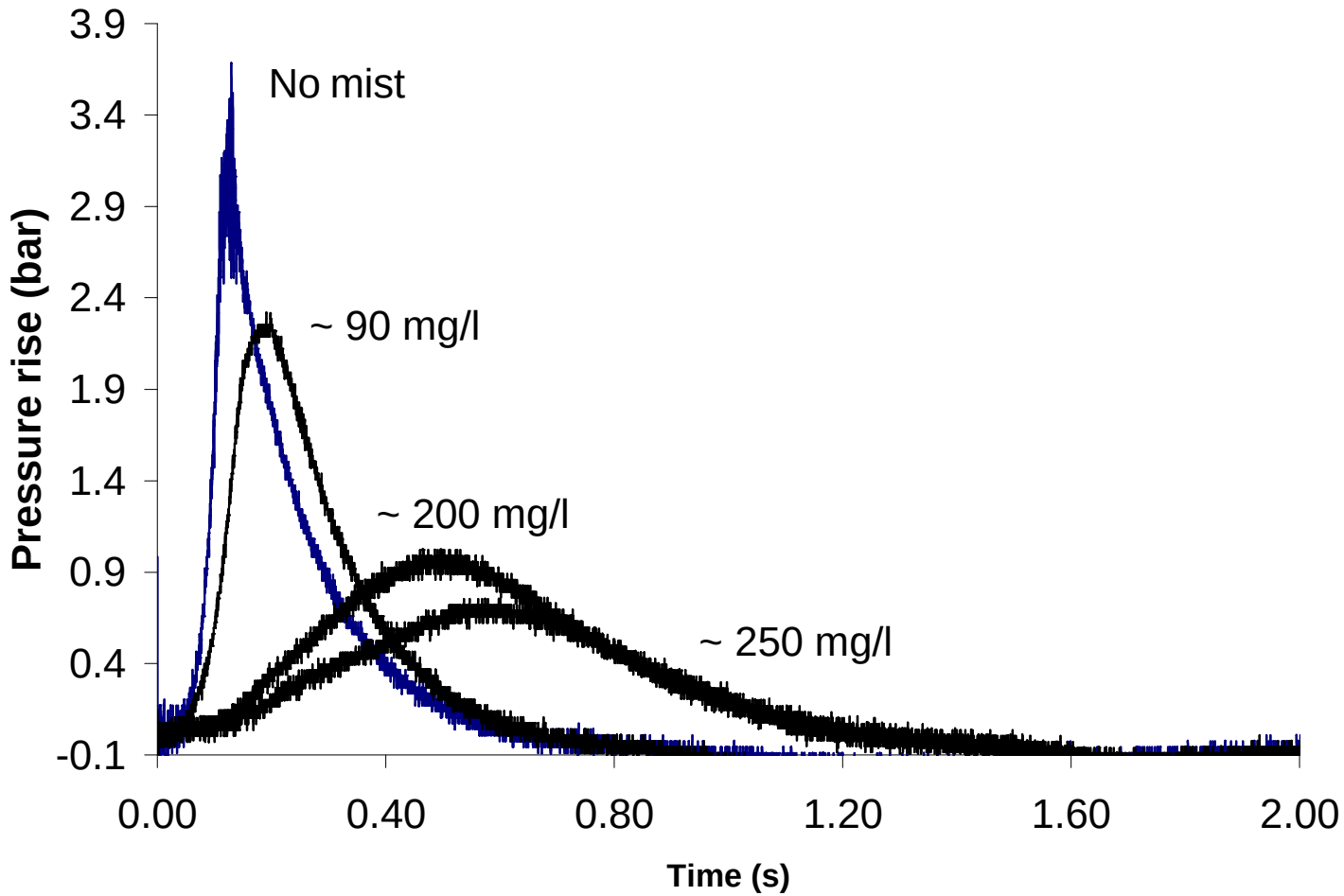
The Effect of Fog on the Explosion Overpressure for H_2-Air (Φ = 0.39) in the (nominally) Unvented Vessel



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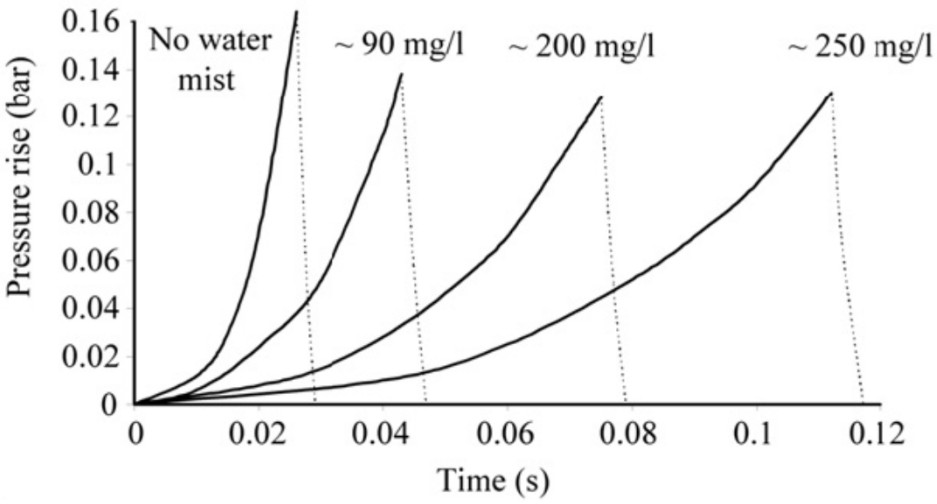
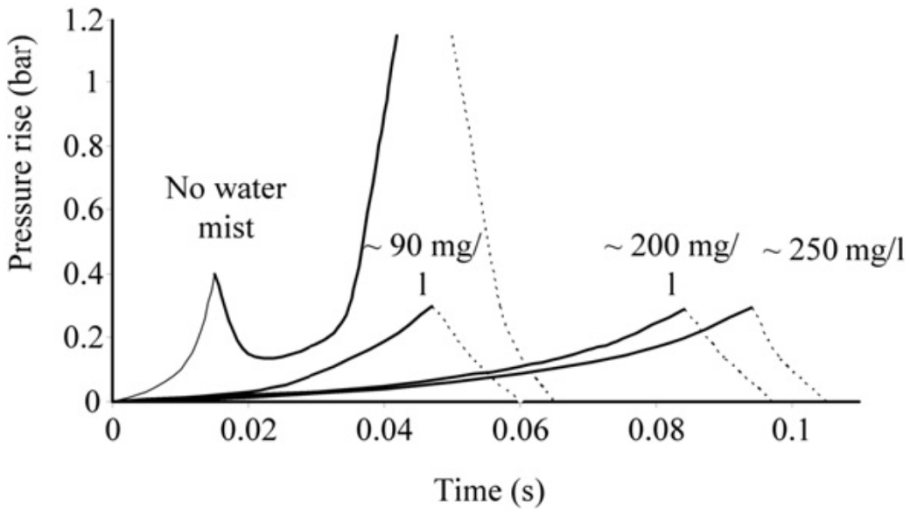
Effect of Fog Density on Explosion Overpressure-Time Histories



200 mm Diameter Vent



100 mm Diameter Vent

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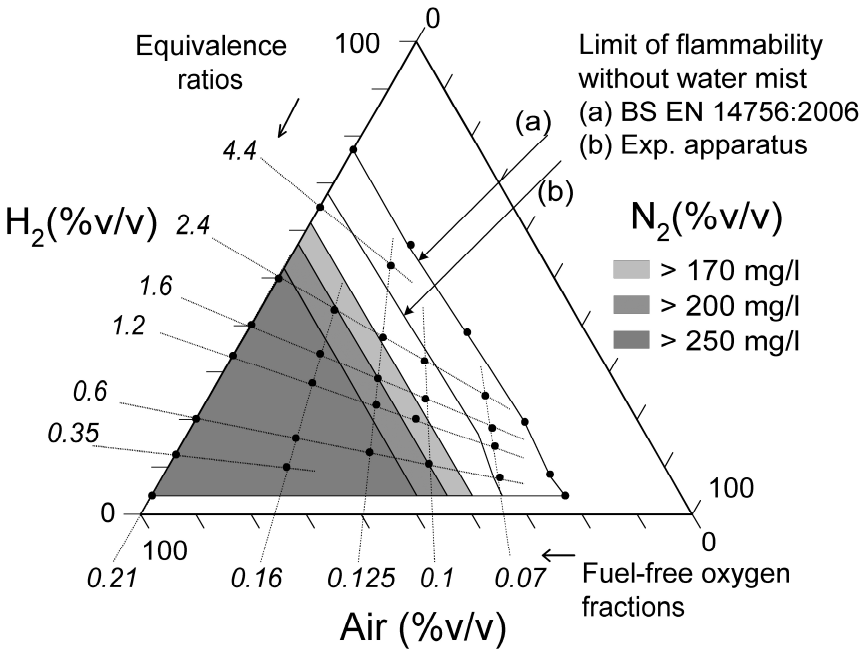
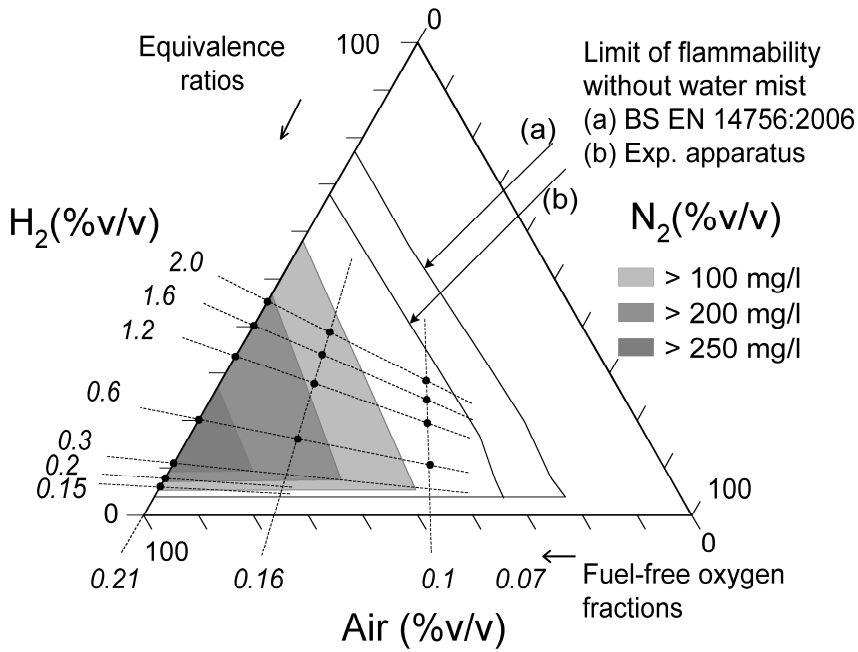
The Effect of Fog Density upon Flammability Limits determined for H_2-O_2-N_2 Mixtures



Fog + Nitrogen dilution



Fog + Nitrogen dilution + NaOH

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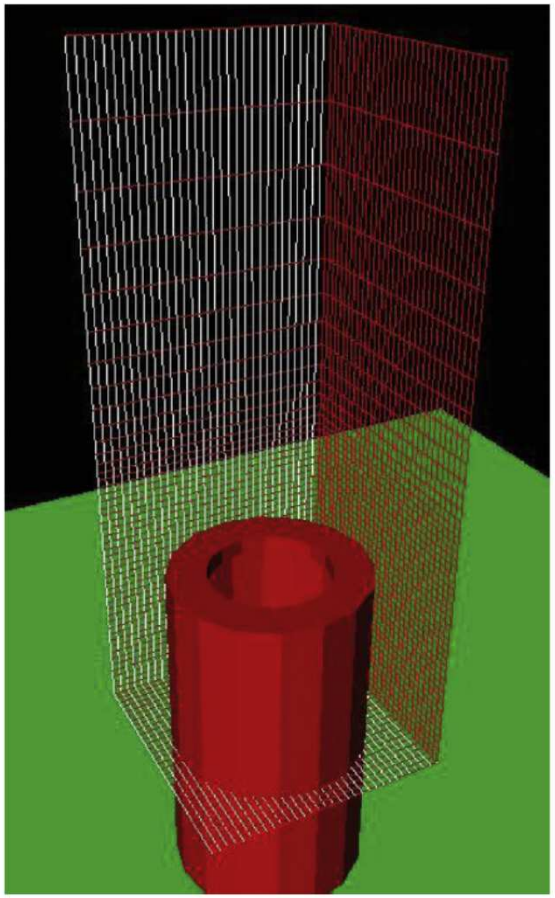
Modelling Studies



- 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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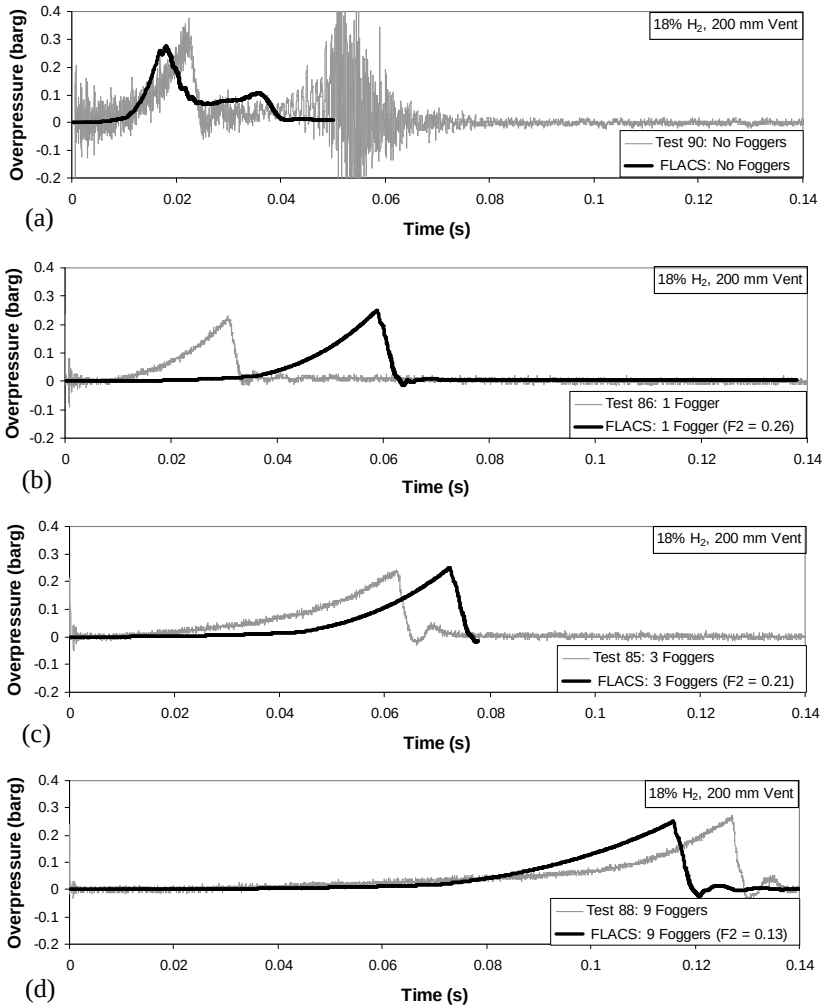
Modelling Studies



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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 + N_2 + NaOH together provides optimal mitigation performance