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Halon alternatives for aviation

Behaviour of fluorinated compounds at sub-inert concentrations in explosion suppression

International Aircraft Systems Fire Protection Working Group Meeting
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Presented by Josephine Gatsonides and Adam Chattaway

CONTENTS OF PRESENTATION

Introduction

- Background / rationale for the work
- Description of Test method
- Results
  - Single agents
  - Mixtures of agents
- Discussion
- Conclusion

RATIONALE FOR THE TEST WORK

Investigation concerning halon replacements

- Adverse behaviour of candidate agents during FAA exploding aerosol can and engine nacelle tests required further investigation into suppression mechanisms.
- NIST had experimental results from Grosshandler, 1994-1997
- Theoretical work of Linteris et al.(2011) concluded with a request to develop a new laboratory-scale experiment to :

  validate understanding and mechanisms,

  explore range of conditions and

  rapidly screen new agents
- Research project for MSc provided opportunity to investigate

WHAT TYPE OF EXPERIMENT?

What information do we want?

- Conditions under which adverse phenomena occur;
- Define parameters and select appropriate test apparatus;
- Test in a reproducible laboratory-scale test set-up and quantify agent limits

WHY A LAB-SCALE EXPERIMENT?

New agent test gone wrong……

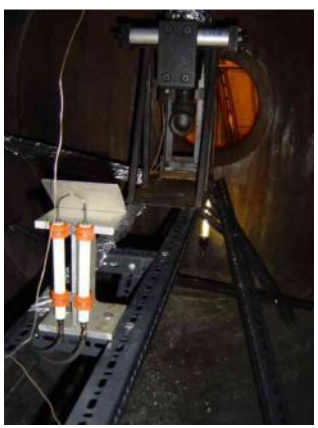
FAA MPS AVIATION MINIMUM PERFORMANCE STANDARD

The MPS for Aircraft Cargo Compartment Fire Suppression Systems contains 4 test elements:

• Bulk-Load Fire

• Containerised-Load Fire

• Surface-Burning Fire Pan



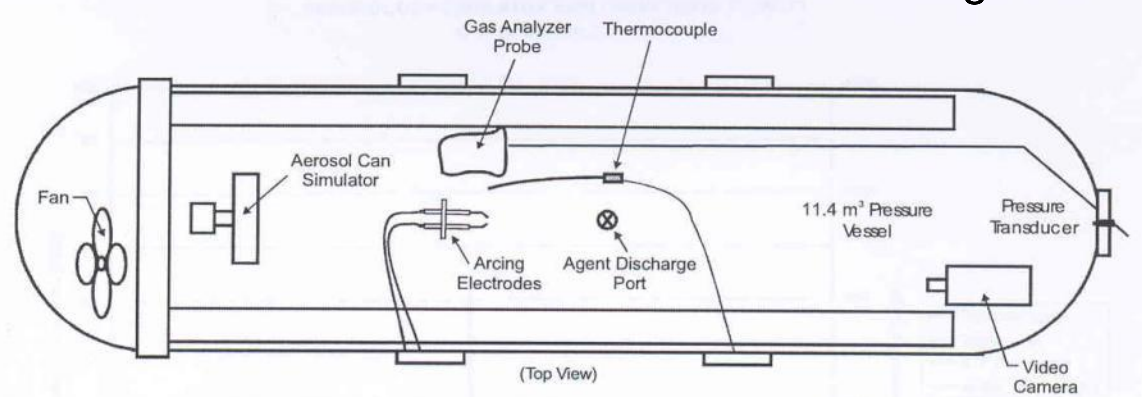


FIGURE 1. PLAN VIEW OF PRESSURE VESSEL SETUP

• Aerosol Can Explosion

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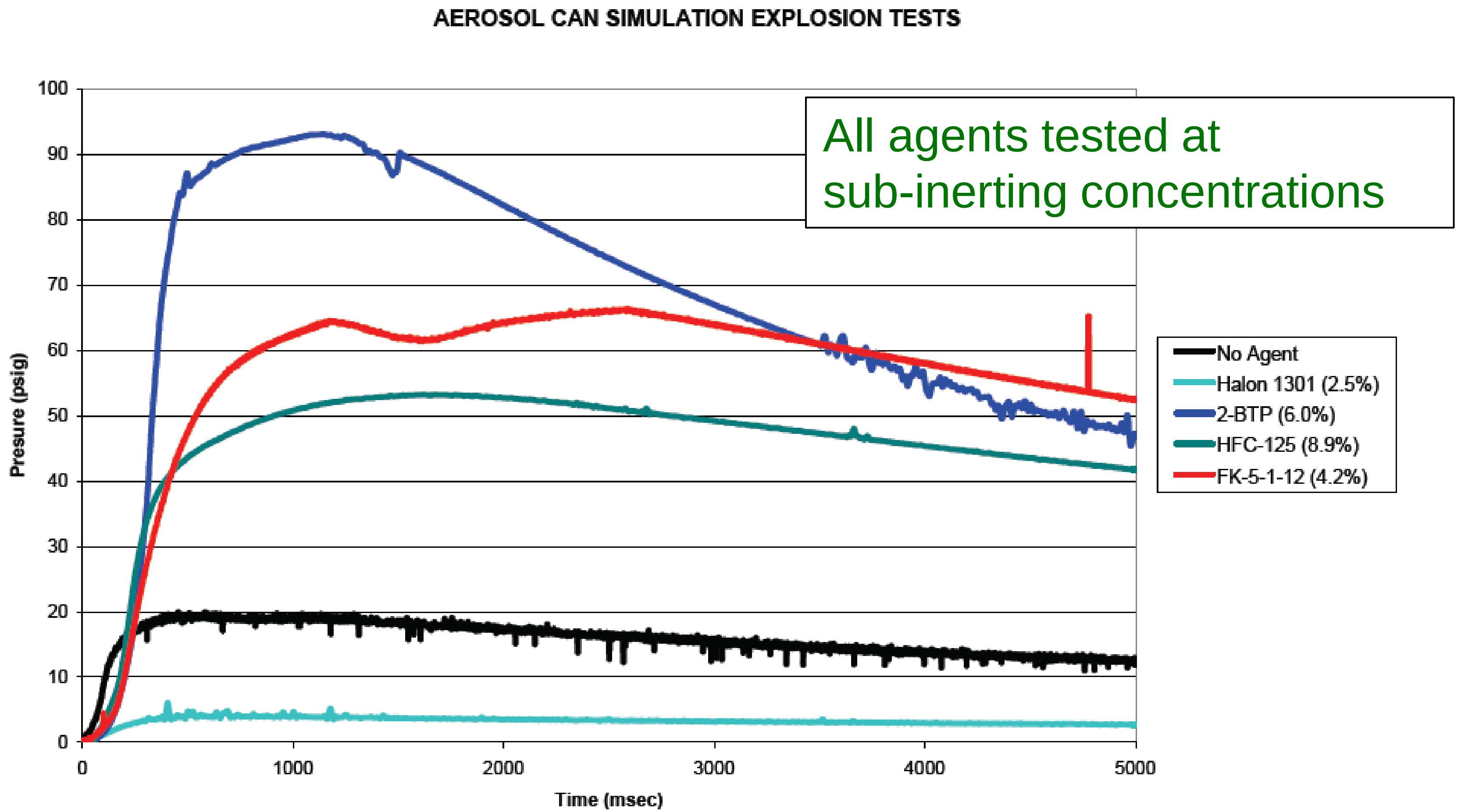
FAA AEROSOL CAN TEST RESULTS

Overpressure issues with halon alternatives



J Reinhardt, : Aircraft Cargo Compartment "Testing Update", FAA meeting, April 2007

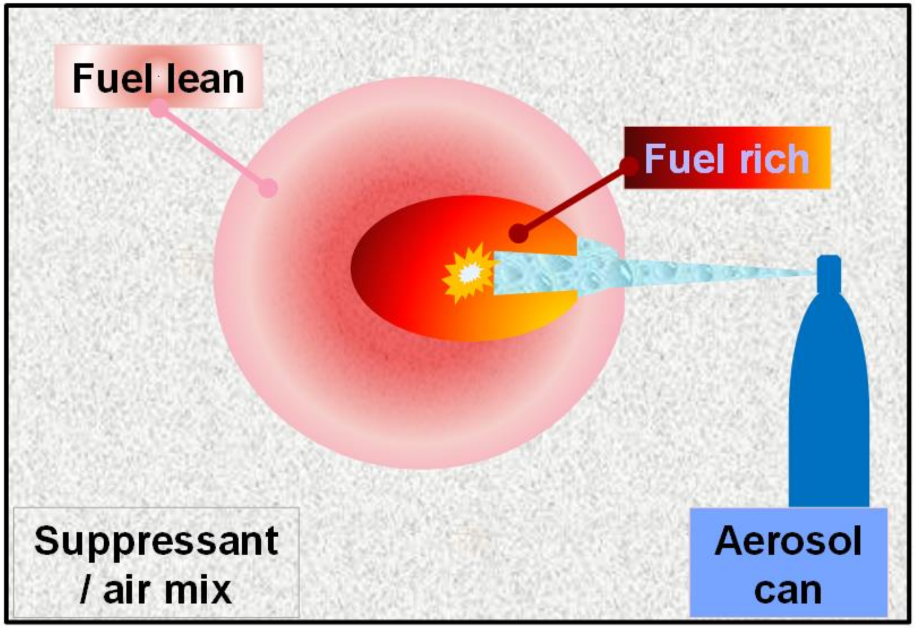
FAA AEROSOL CAN TEST

Test procedure

A mixture of propane and ethanol is discharged across sparking electrodes, combustion / explosion pressure is measured. Uneven fuel distribution (fuel rich near spark, fuel lean further away) means variable stoichiometry. Conditions are difficult to control and repeat, modelling of the event is complicated.

In real life, homogeneous suppressant distribution and concentration are not guaranteed.

- Air leakage / ventilation of cargo hold.
- Distribution obstructed by cargo / containers
- Slow discharge, 1 min vs 10 sec



CANDIDATE AGENT TEST REQUIREMENTS

Information wanted

- Performance of agents at various sub-inert concentrations and air/fuel ratios (lean, rich & stoichiometric)

How to achieve this?

- Back to basics; single fuel tested in more controlled environment
- Propane is more volatile than ethanol
- Propose to use propane as reference to test candidate agents
- Test methodology based on internationally accepted Standards to design an easily reproducible screening test

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EXPLOSION TEST VESSEL

Test methodology

- Set-up of test apparatus and methodology is based on international ASTM and BS EN Standards regarding determination of explosion limits of gases and vapours
- Test Vessel used is a 43 L Sphere
- Spark ignition with electrodes at centre of vessel
- Pressure transducers to record filling and explosion event
- Thermocouples to measure flame detachment and speed
- Fuel is propane
- Gas concentrations established by partial pressure during introduction in vessel. Verified by mass and FTIR apart from nitrogen which was inferred from O_2 measurements

EFFECT OF SIZE

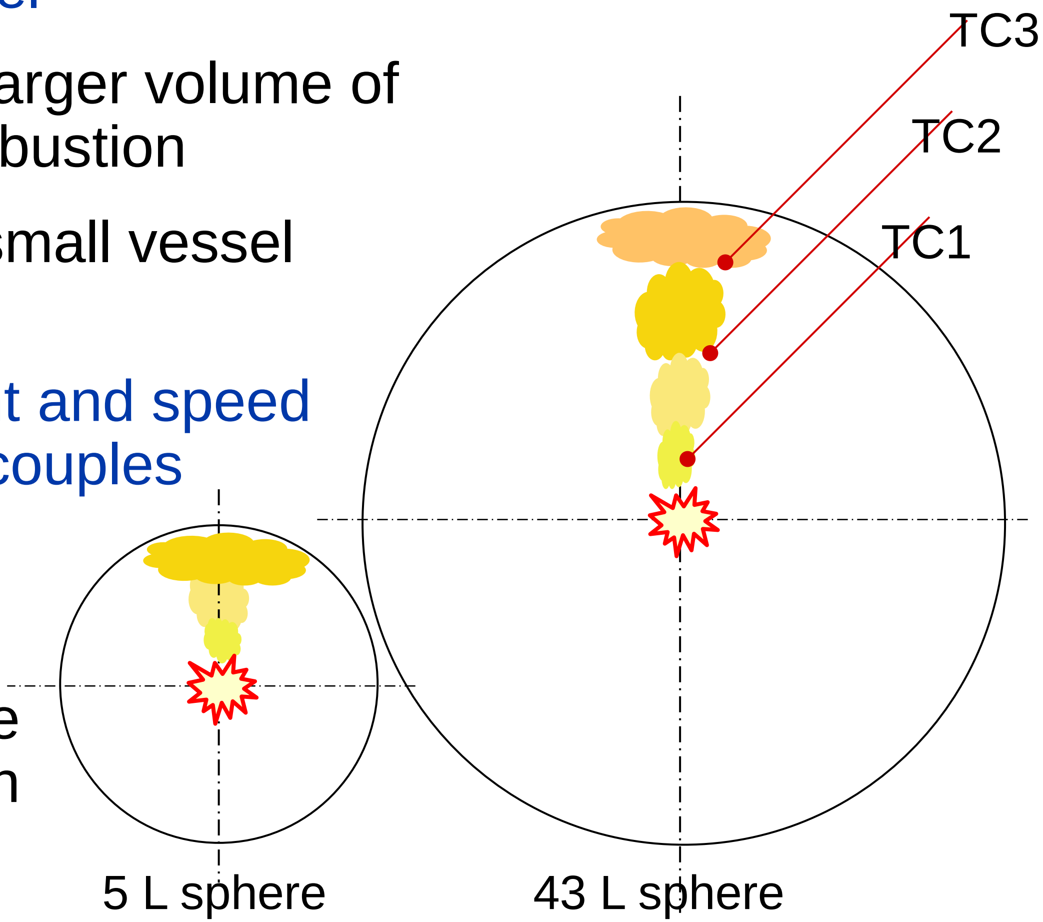
Considerations in selecting scale of experiment

At critical limits only a small part of gas volume combusts, due to buoyancy of flame kernel

- In small vessel a relatively larger volume of contents is involved in combustion
- Measured pressure rise in small vessel higher than in larger vessel

Combustion, flame detachment and speed can be measured with thermocouples

- Larger vessel provides more space between TC's;
- Easier to detect temperature changes / flame propagation



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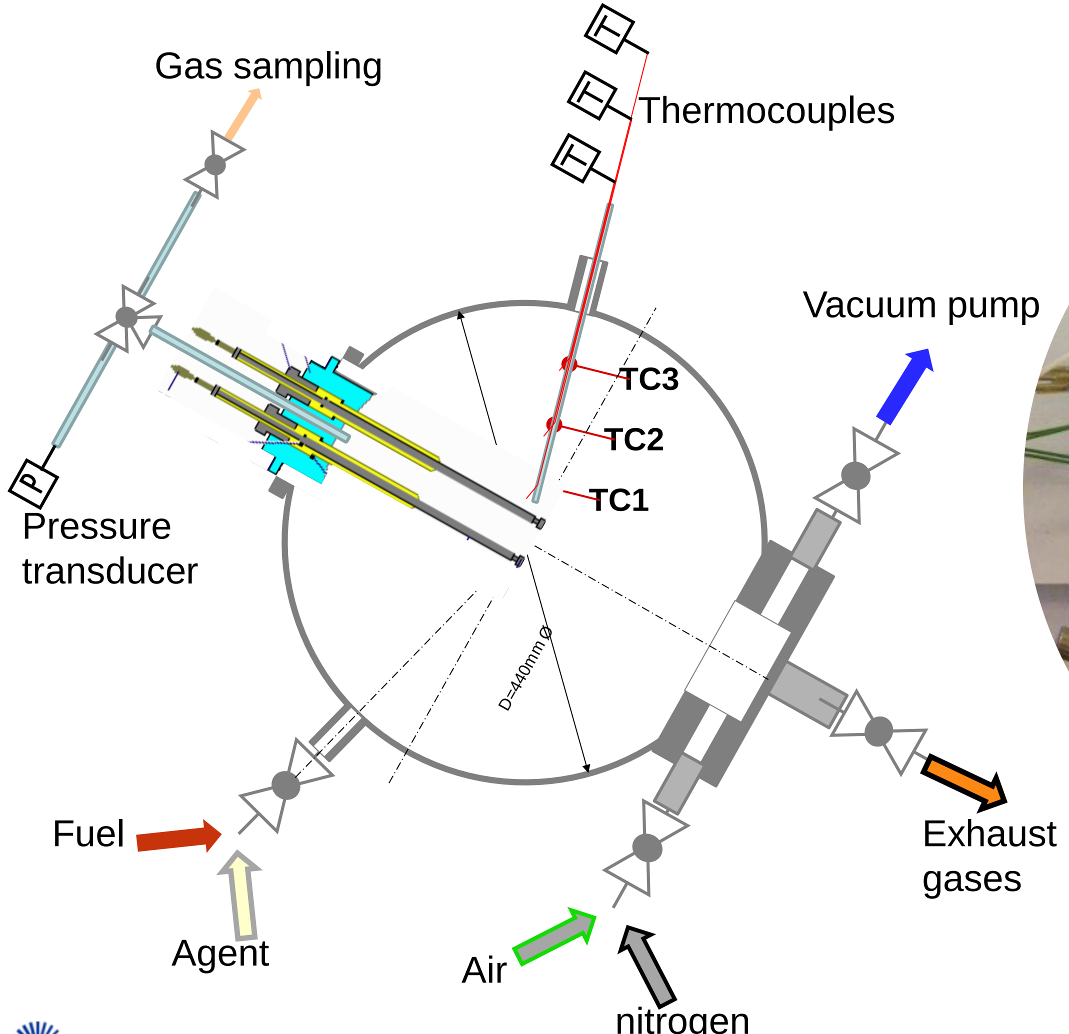
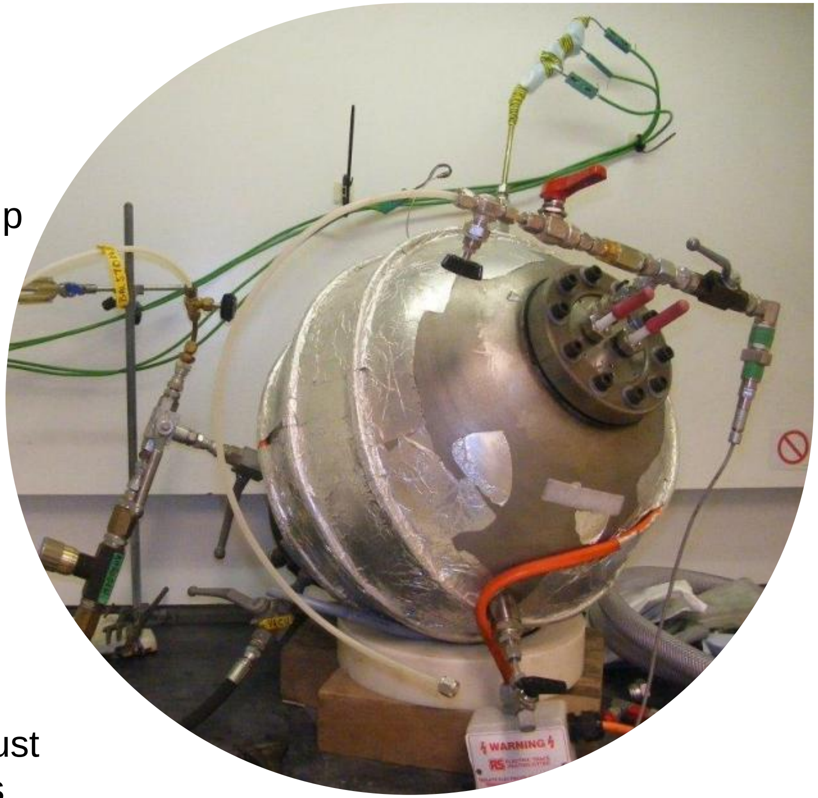
TEST APPARATUS

Schematic 43 L sphere





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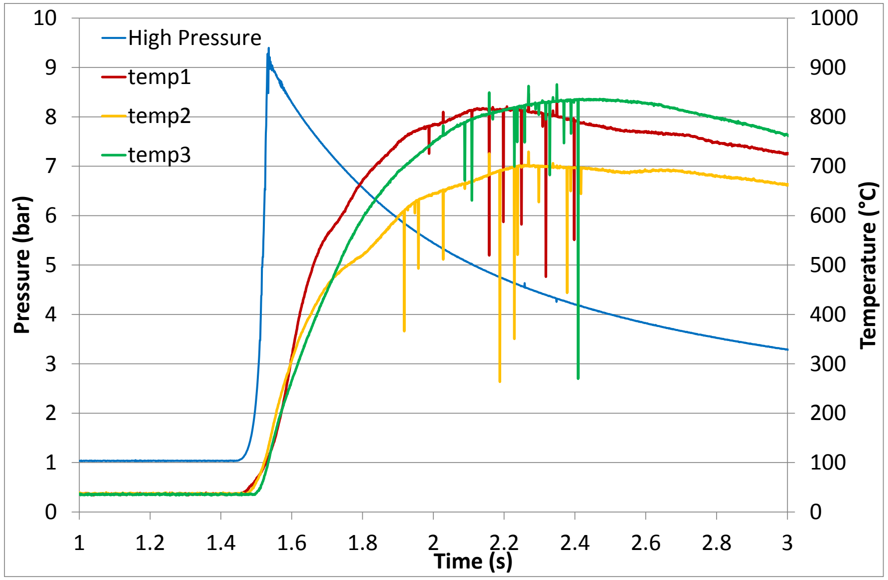
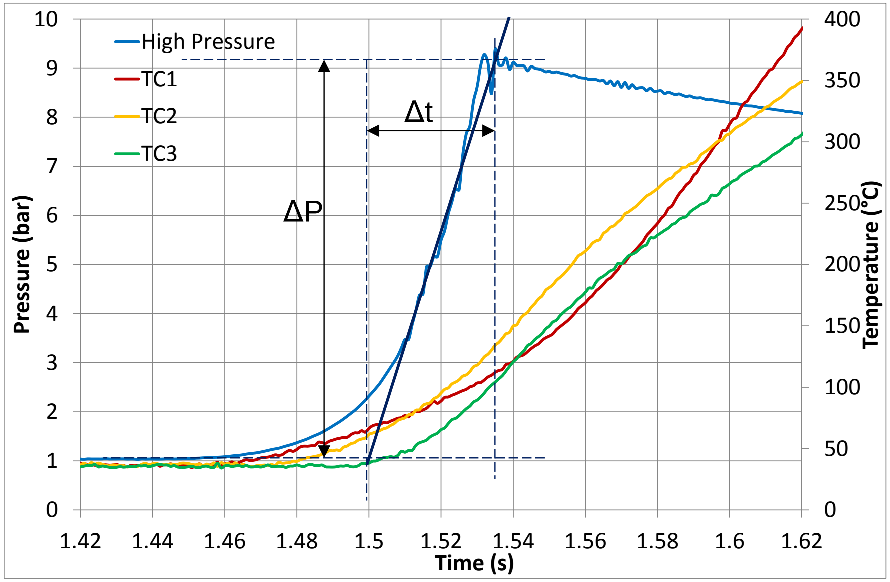
VALIDATION OF 43 L SPHERE

~Stoichiometric (4.15 vol%) propane/air explosion

Pressure / temperature graph of unsuppressed explosion

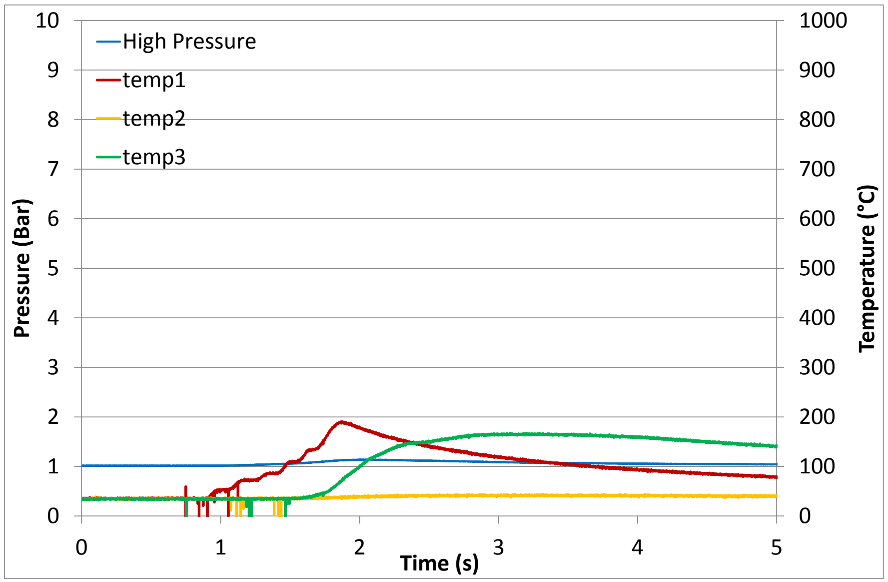


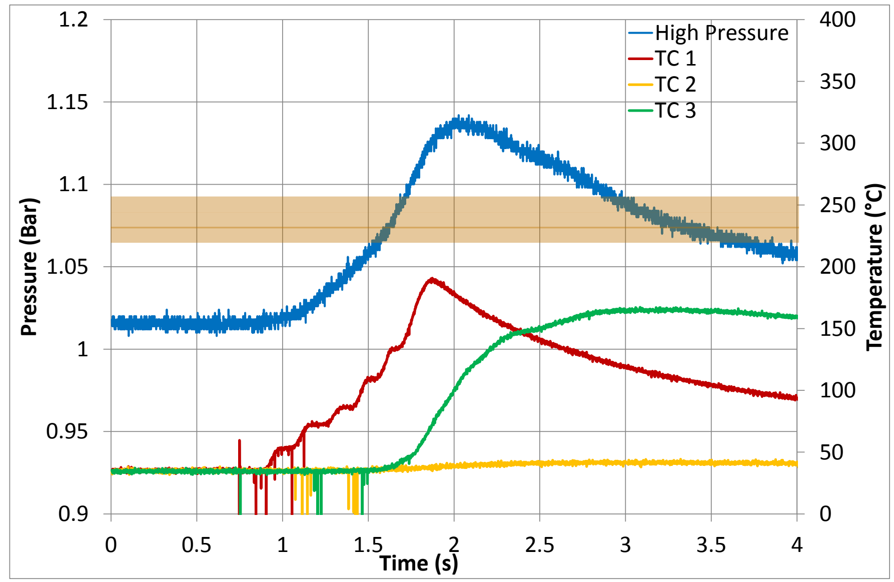


- Rate of pressure rise agrees with published values
- Temperature measurement clearly shows flame propagation

VALIDATION OF 43 L SPHERE

Lean (2.1 vol%) propane/air explosion



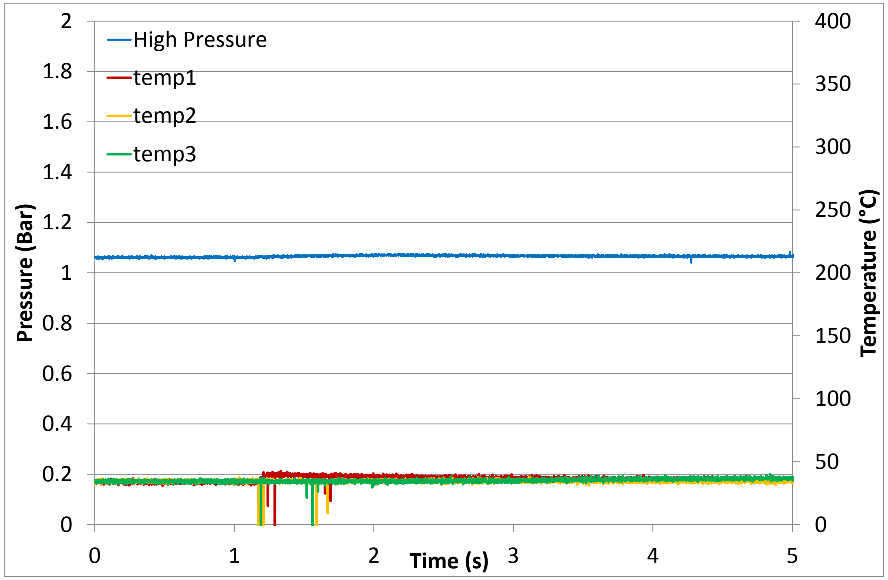


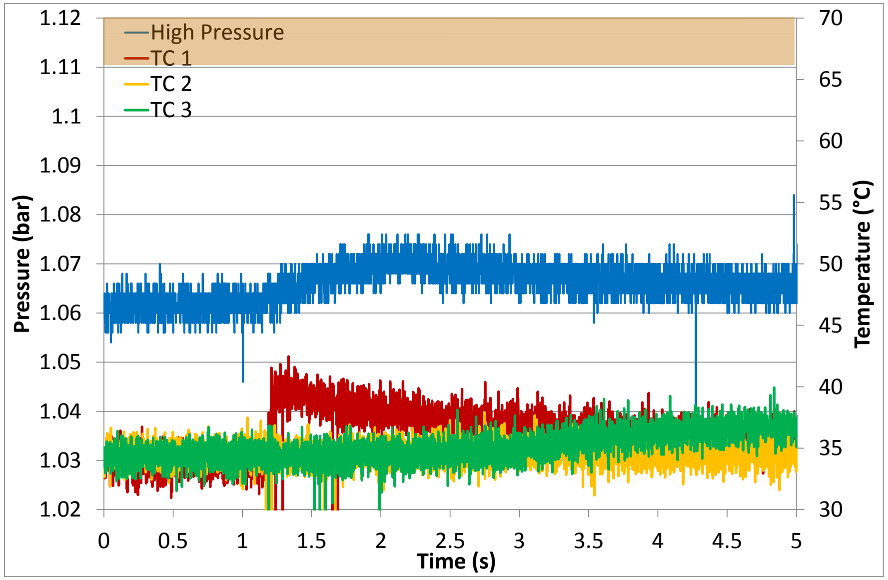
= explosivity limit 5% x P_0(BS EN1839:2012 / BS EN 15967:2012) → 7% x P_0(ASTM E2079-07)

- Sensitive transducer measures slightest pressure rise
- Temperature measurement indicates phases of flame detachment and propagation at lean limit

VALIDATION OF 43 L SPHERE

Lean (2.05 vol%) propane/air explosion

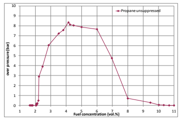
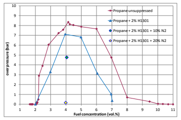
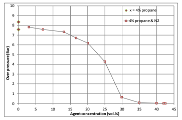
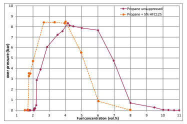
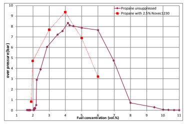
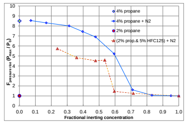




= explosivity limit 5% x P_0(BS EN1839:2012 / BS EN 15967:2012)

- Temperature measurement indicates phase of flame detachment
- Recordable temperature measurement in sphere can replace visual observation of flame detachment in tube

TEST MATRIX

Test type		No. of Tests
Unsuppressed propane baseline tests		37
Propane + Halon1301 baseline tests		7
Propane + nitrogen baseline tests		11
Propane + HFC125		41
Propane + Novec1230		6
Propane + HFC125 + nitrogen		8

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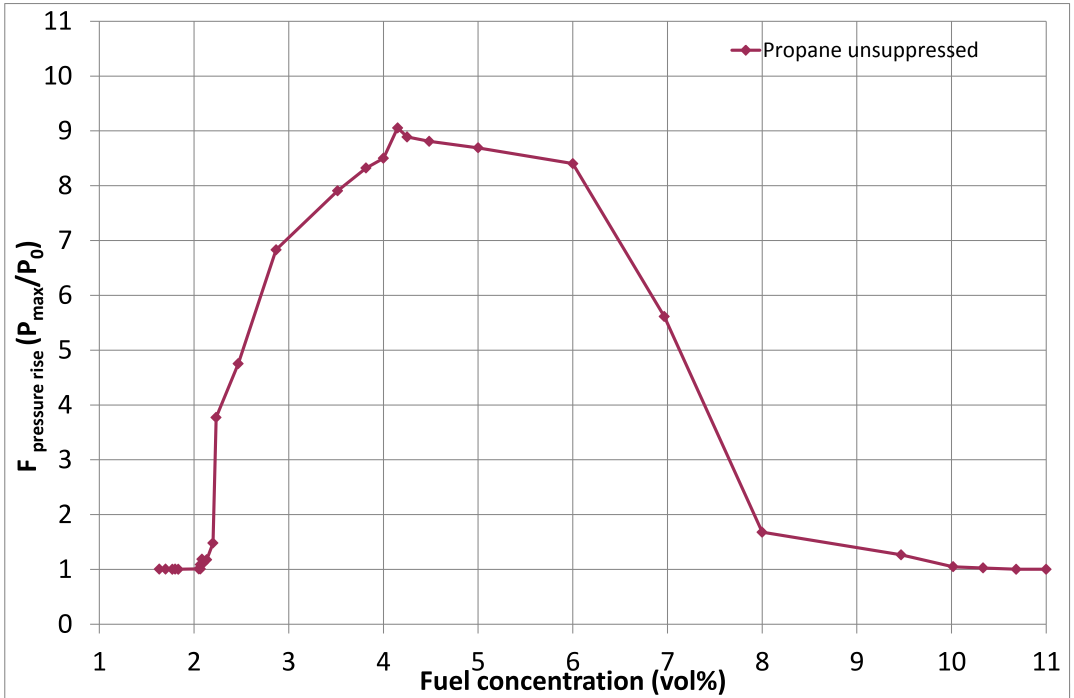
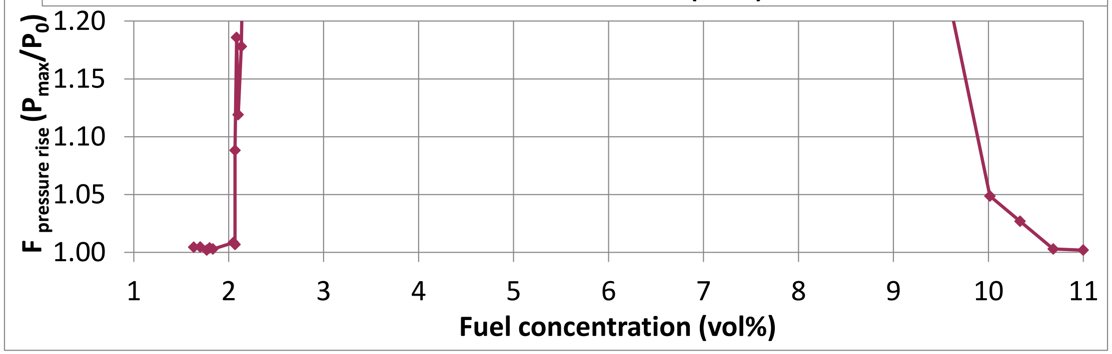
PROPANE UNSUPPRESSED

Explosion overpressure

- Achieved maximum pressures corresponding with literature.
- LEL and UEL based on pressure limit correspond with literature.
- BS EN 1839 states that tube method (flame detachment) gives wider flammability range.
- Analysing TC data confirms combustion at very low overpressures.





Propane	= C_3H_8
LFL	= 1.7 - 2.1 vol%
Stoich.	= 4.0 vol%
UFL	= 9.6 - 10.5 vol%

HALON1301 BASELINE

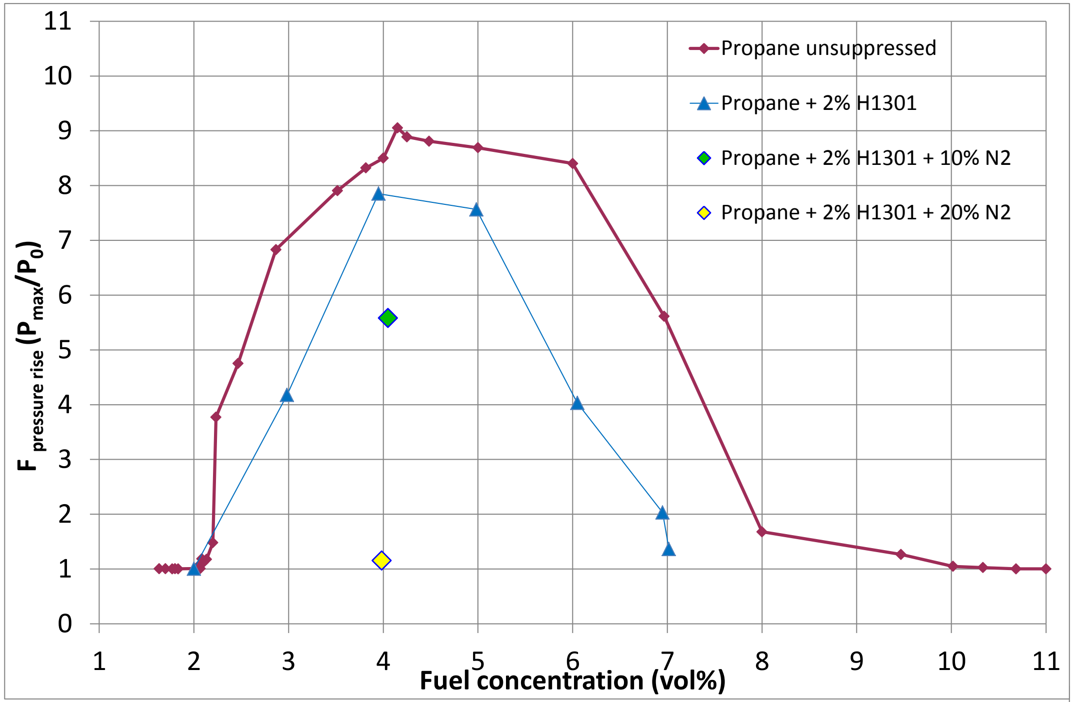
Effect of sub-inerting concentration

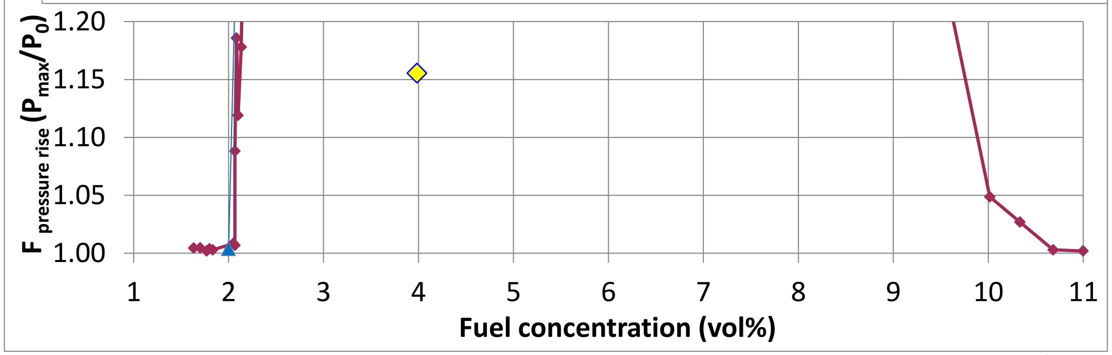
- **2%** Halon1301 is approx. **0.3x** inerting concentration
- Mitigates propane explosion pressure
- Additional nitrogen (10% and 20%) aids further suppression
- Positive synergistic effect : 0.3x Halon + 0.5x N2 provide nearly 100% full inerting
- Confirms FAA test data (DOT/FAA/AR-TN08/49)

Halon 1301 = CF_3Br

Inert % $_{prop}$ = 6.1 vol%

Boiling point = -58 C



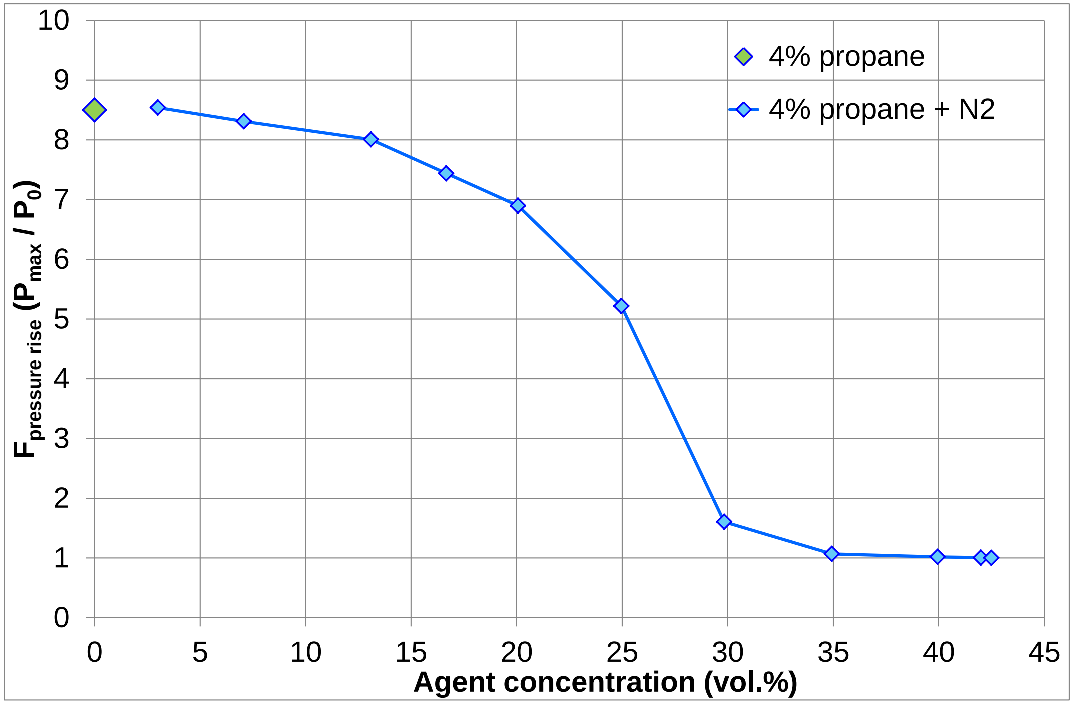


NITROGEN BASELINE

Commonly used industrial inert gas

- From 30% (~2/3 of full inerting concentration) onwards significant decrease of explosion pressure

- OBIGGS available and proposed by FAA to use in combination with halon replacements in low rate discharge to make up for ventilation leakage



Nitrogen = N_2

Inert % $_{prop}$ = 42 vol%

Boiling point = -195.8 C

CANDIDATE AGENTS

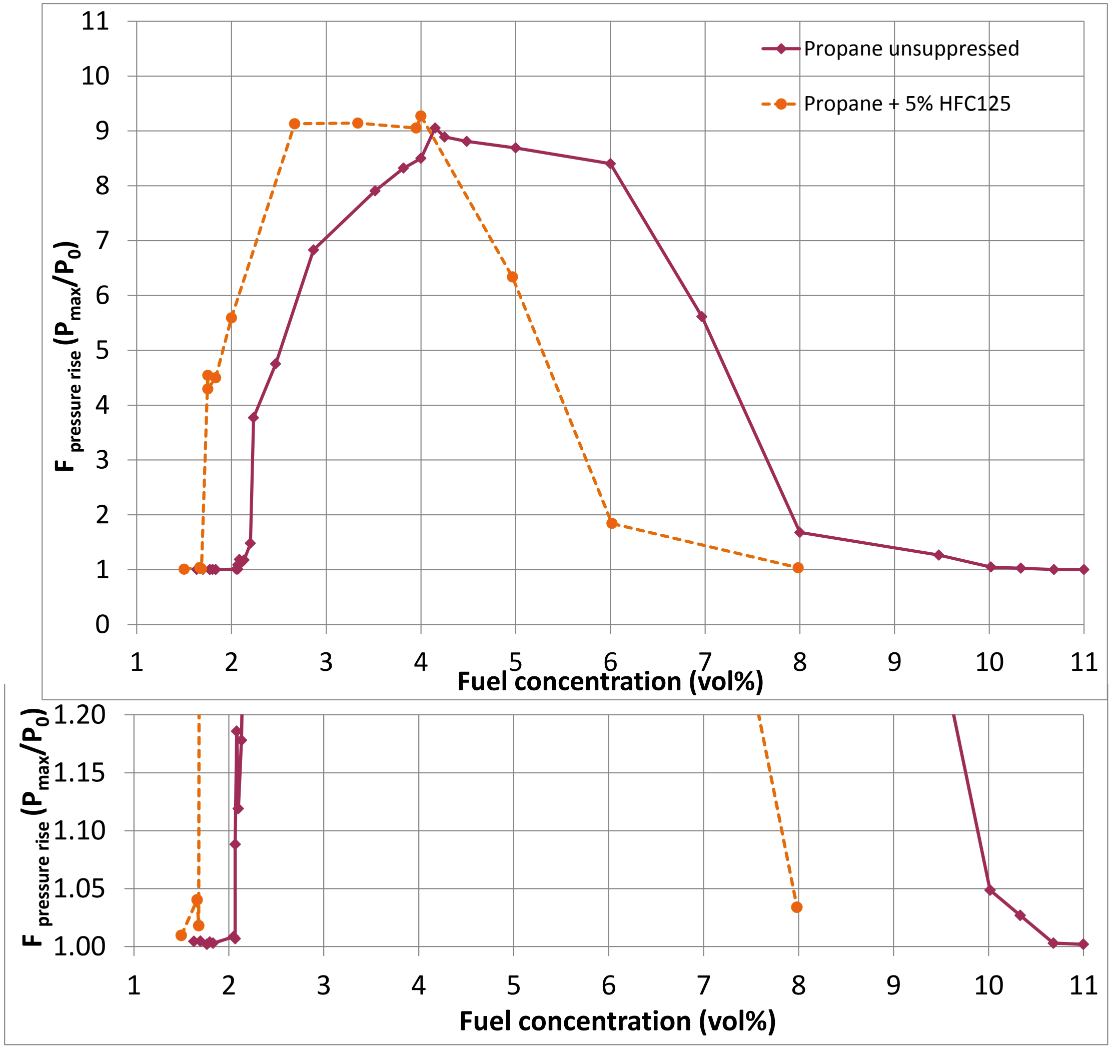
Test parameters

HFC125	5.0 vol%	Propane	Variable %		
HFC125	Variable vol%	Propane	4 vol%		
HFC125	Variable vol%	Propane	2 vol%		
HFC125	5.0 vol%	Propane	2 vol%	Nitrogen	Variable %
Novec1230	2.5 vol%	Propane	Variable %		

INERTING WITH HFC125

Sub inerting concentration

- **5%** HFC125 is approx. **0.3x** inerting concentration
- Shift to lean side of flammability curve for propane indicates that a low % HFC125 combined with a low % propane acts as fuel
- Added to concentrations propane higher than stoichiometric mitigates flammability as if an overly rich mixture is achieved



HFC125 = C_2HF_5

Inert% $_{prop}$ = 15.7 vol%

Boiling point = - 49 ^oC

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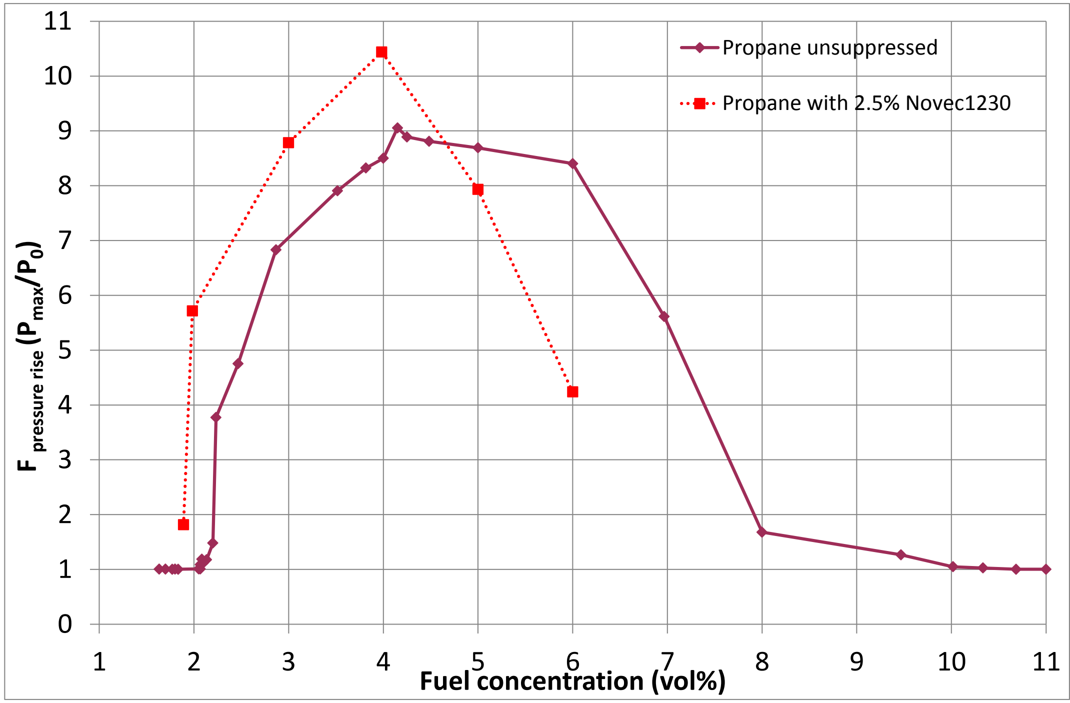
INERTING WITH NOVEC1230

Sub inerting concentration

- **2.5%** Novec1230 is approx. **0.3x** inerting concentration
- Novec1230 shows similar behaviour as HFC125
- Lean mixture: agent exacerbates the explosion
- Rich mixture: agent mitigates explosion



Novec1230 = $C_6F_{12}O$

Inert%$_{prop}$ = 8.1 vol%

Boiling point = 50 ^oC

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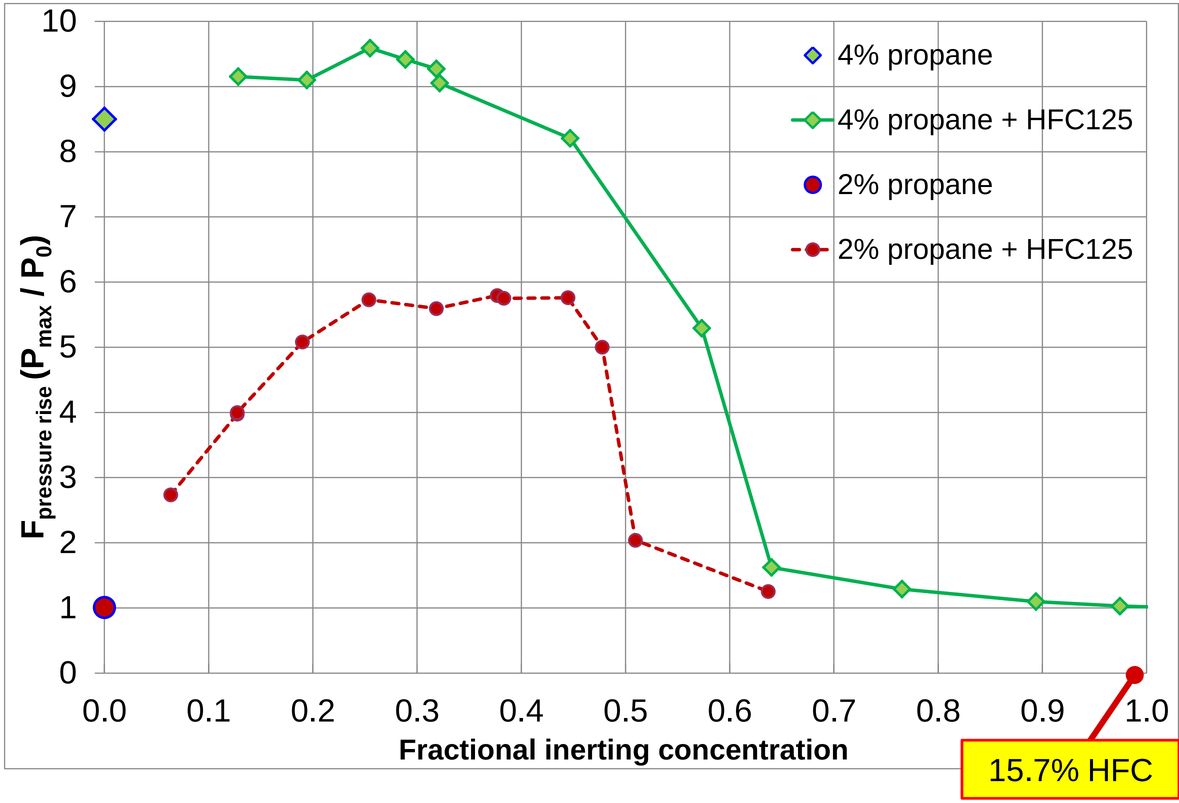
INERTING WITH HFC125

Sub-inerting against 2% and 4% propane

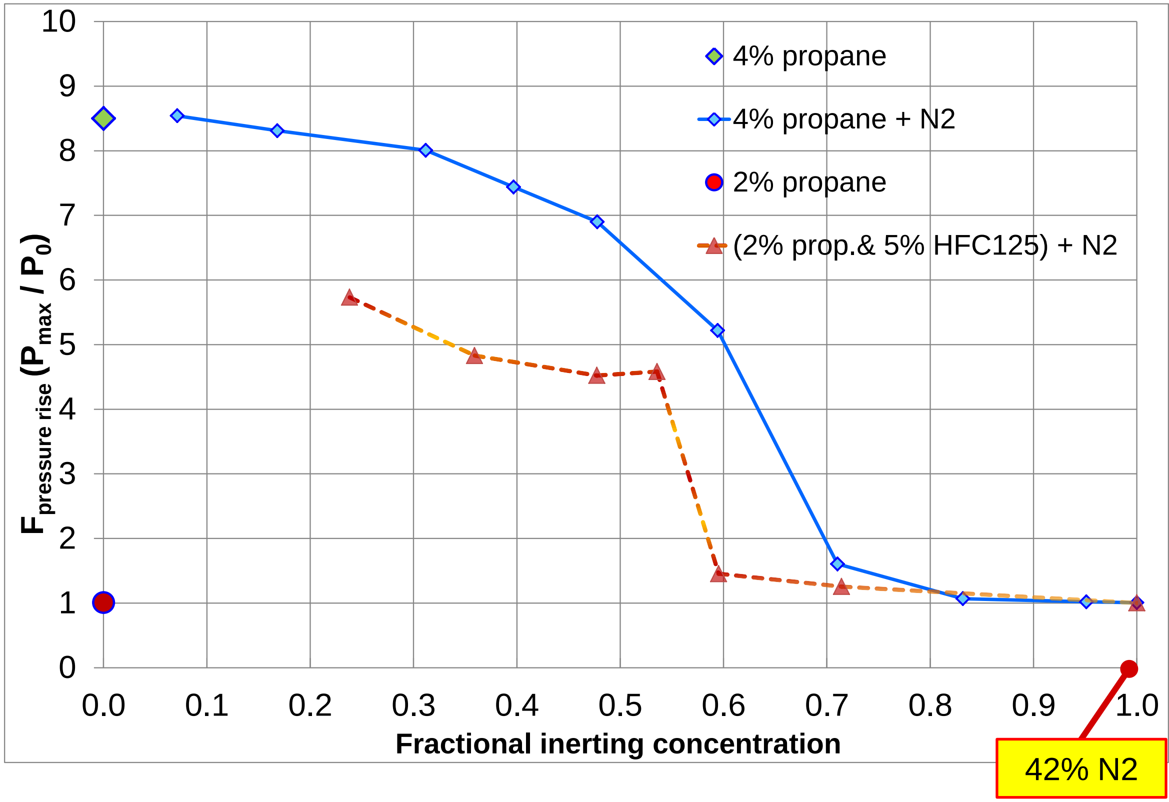
- 0.1x up to 1x full inerting concentration of HFC125
- Against 4% propane a curve reminiscent of N2
- Against 2% propane non-flammable becomes explosive
- Both need at least 0.6x of full inerting concentration to be effective
- From 3 to 7 vol% HFC125 the most explosion mixtures occur



INERTING WITH NITROGEN

Sub-inerting against 2% propane-5% HFC125 mix

- Inerting with nitrogen starts to be effective from 0.6x of full inerting concentration of 42 vol%
- At lean fuel concentrations no positive synergy observed in combining HFC125 with nitrogen
- In these tests the 2% Propane / 5% HFC125 can be regarded as a fuel mix



SUMMARY OF RESULTS

Explosion mitigating properties

- Halon 1301 always mitigates propane explosions
- Adding nitrogen to Halon 1301 at sub-inert concentrations enhances its performance, total amount suppressant needed of combination is less than individual components
- HFC125 and Novec1230 when tested at below inerting concentration enhance fuel lean explosions, but mitigate fuel rich explosions
- Adding HFC125 to nitrogen at sub-inert concentrations makes no difference to its performance, still full concentration nitrogen needed

VALIDATION AS A SCREENING TOOL

Performance of laboratory-scale experiment

- One of the objectives of this work was the development of a laboratory-scale experiment to rapidly screen new agents
- The 43 L sphere test set-up is compliant with recent international standards and produces accurate and repeatable results.
- Only small amounts of agent, 10g - 40g per test, needed.
- Testing candidate agents at various below inerting concentrations against propane explosions provides a good indication for their behaviour against the aerosol can tests

ACKNOWLEDGEMENTS

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in cooperation with

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Energy Research Institute, University of Leeds, UK

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THANK YOU FOR YOUR ATTENTION

Questions?