IDENTIFICATION AND LAB-SCALE TESTING OF NEW FIRE EXTINGUISHING AGENT BLENDS FOR CARGO COMPARTMENTS

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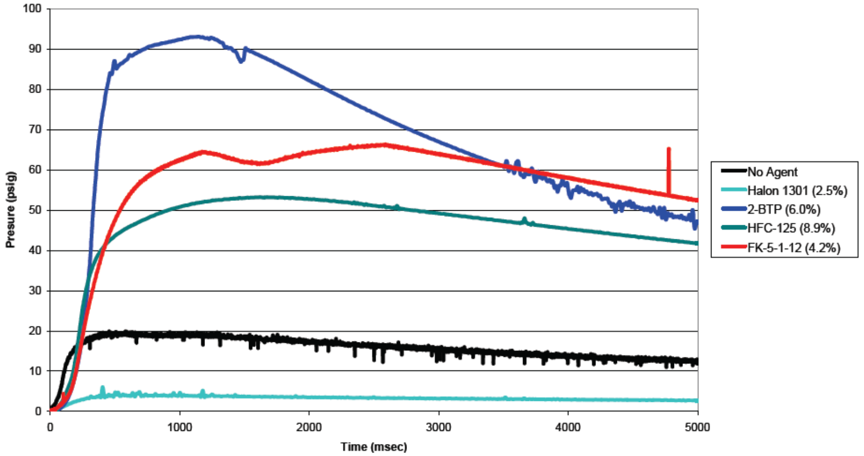
INTRODUCTION

Why are we carrying out Inerting tests?

- The FAA Aerosol Can Test was devised to simulate the effects of an aerosol can exploding in a cargo fire situation and damaging cargo liners
- In general, agents such as Halon 1301 inert this test at a certain concentration which defines their low-rate discharge (LRD) concentration.
- However, some halon replacement agents when tested at below their inerting concentration actually made the aerosol can explosion test (ACT) worse, in that higher pressures were developed.
- **We can screen agents to predict their performance against the FAA Aerosol Can Test**
- **Will be added to the new version of MPS Standard as a prerequisite test**



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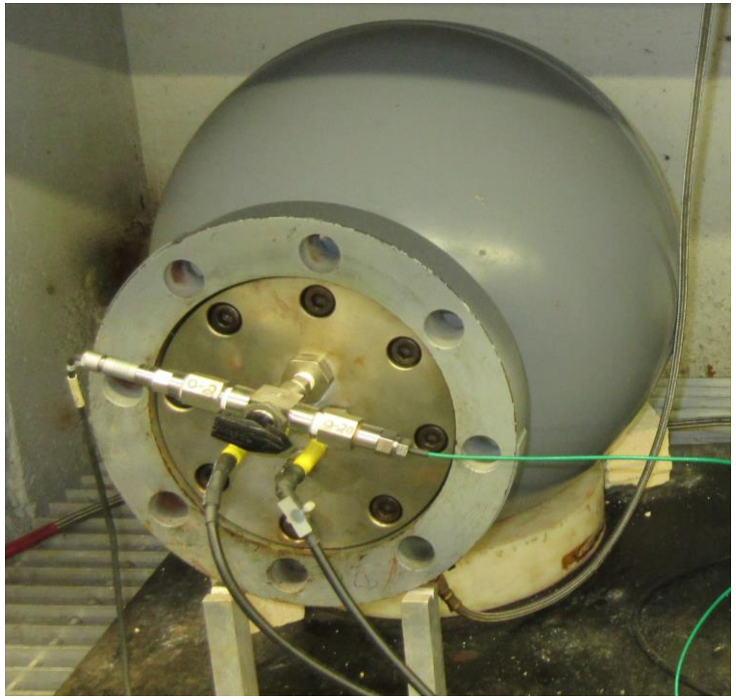
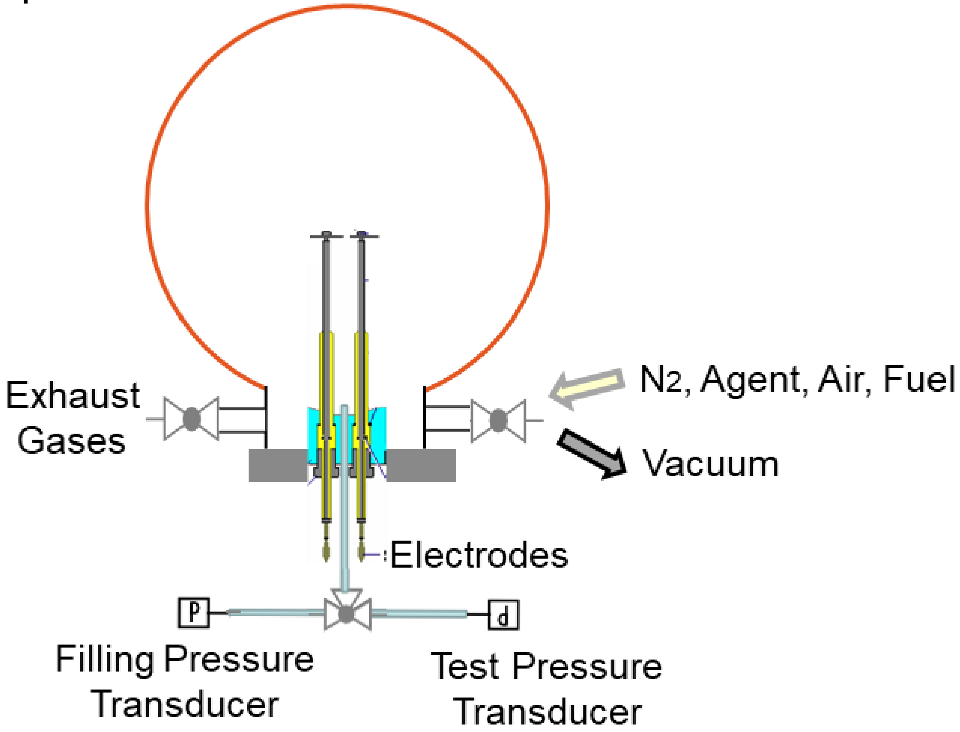
DEVELOPMENT OF A SCREENING TEST

Use of small-scale test to predict performance in aerosol can test

Kidde 43 L Inerting Sphere:



Top view:



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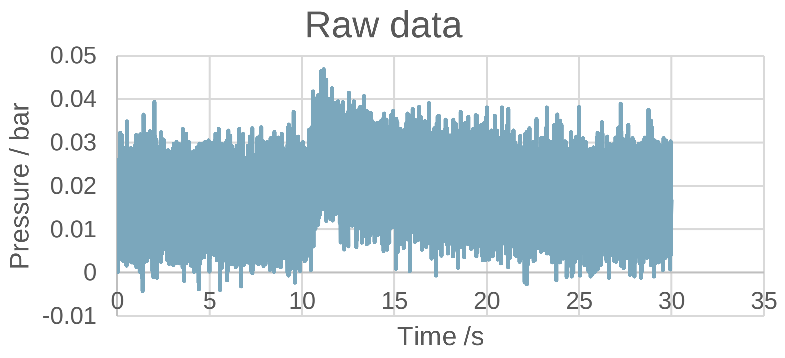
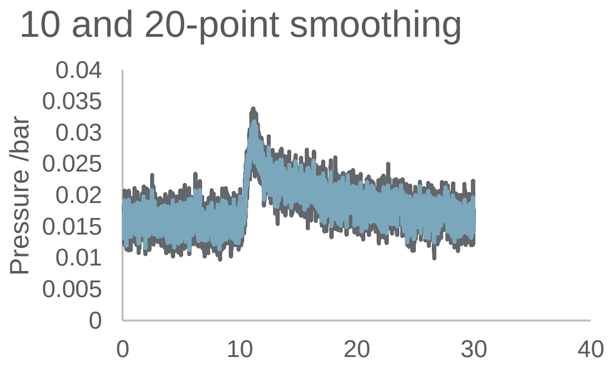
TEST METHODOLOGY

Small-scale test to predict performance in aerosol can test

- Sphere evacuated, propane, agent(s) added stepwise by partial pressure
- Air introduced to achieve 1 atmosphere
- Wait 15 minutes for equilibrium (heat sphere if necessary to disperse less-volatile agents)
- Start high speed DAQ
- Activate ignition spark for 1 second
- Record results, evacuate and purge sphere
- If testing near pass/fail criterion pressure rises are small, so signal noise can be an issue
  – 10- or 20-point smooth in Excel cleans the data





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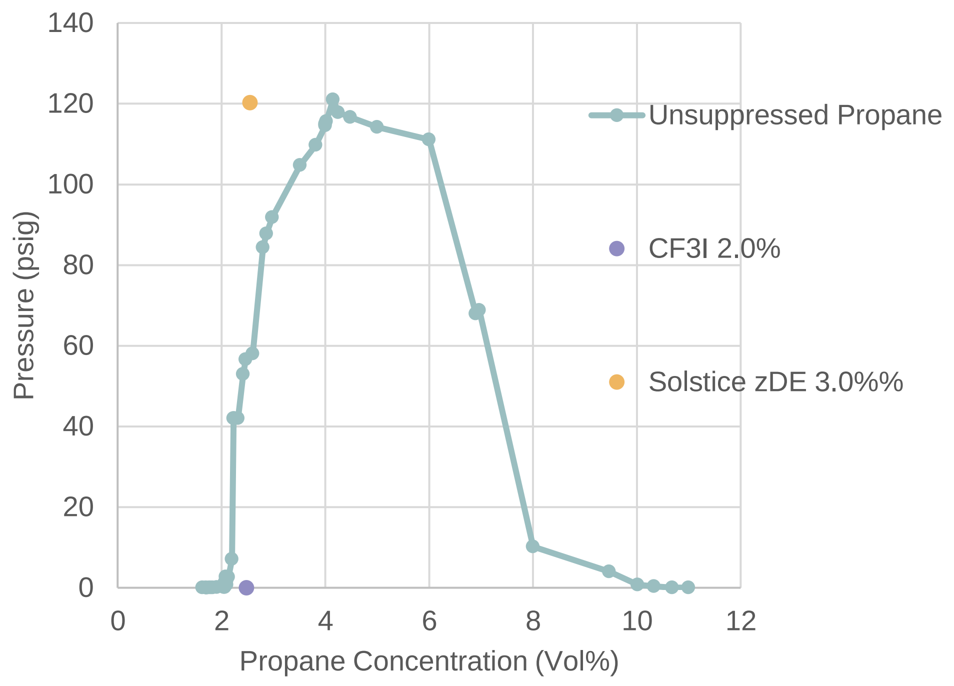
TEST METHODOLOGY

Small-scale test to predict performance in aerosol can test

- Recalling that stoichiometric propane concentration in air is 4.0%
- Use this concentration to identify the peak inerting concentration of the new agent or blend
- Then test new agent or blend at lean propane/air ratio (2.0-2.5%) at approx. 1/3 peak inerting concentration
- Data for CF_3I and HCFO-1233zd(E) shown, illustrating the two results



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TESTING WITH BLENDS

Revised test methodology

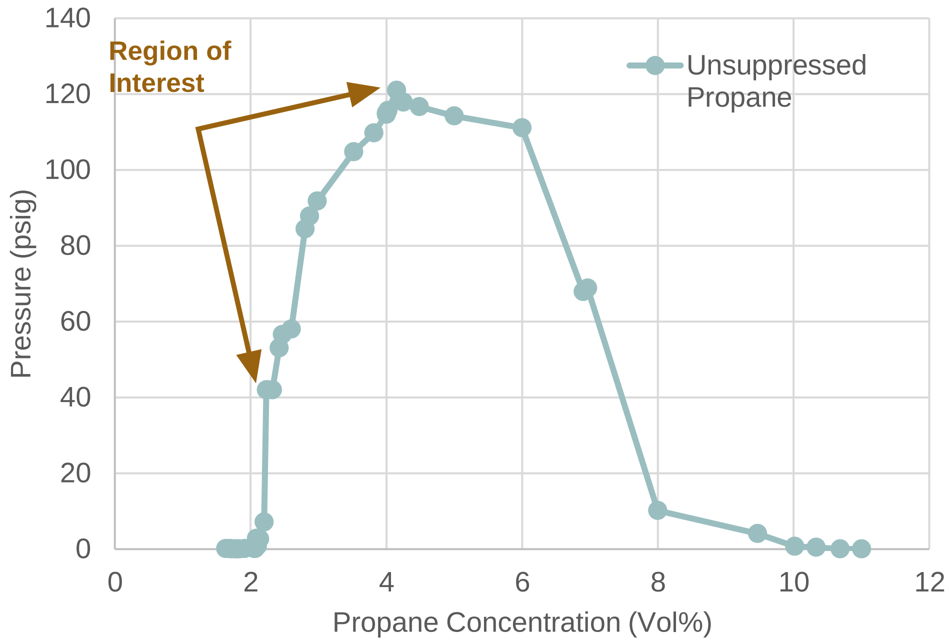
When evaluating blends of a “flammable” agent and a non-flammable agent there are two questions that need to be answered:

1. *What is the minimum proportion of the non-flammable agent that prevents the enhancement of the propane-air explosion on the lean side?*
2. *Having established the minimum proportion of the non-flammable agent, what is the inerting concentration of the blend at peak flammability (i.e., 4 vol% for propane-air)?*

REFINING THE SCREENING TEST

Prediction of performance in ACT

- Having established blends that are not likely to make ACT worse, can we devise a test to predict Pass / Fail criterion?
- The ACT has an overall "severity" somewhat less than stoichiometric propane/air
- There ought to be a propane/air ratio that has similar severity to the ACT
- Evaluate performance of Halon 1301 (3%) against various concentrations between LFL (~2% propane in air) and peak limit (4% propane in air)
- Use this concentration to test new agents



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REFINING THE SCREENING TEST

Prediction of performance in ACT

- Testing with Halon 1301 various propane/air stoichiometry were evaluated such that 3% halon could successfully suppress the explosion but less than 3% could not
- 3.3% Propane/Air was chosen
- The concentration was then selected to evaluate CF_3I.
- 3.2% CF_3I appears to be equivalent to 3% Halon 1301 in its ability to control a fuel lean propane/air explosion
- This concentration was shown to control Aerosol Can Test as reported by Boeing at 2019 Triennial Conference

#	Test	Propane %	CF3I %	Pressure / bar	Pressure / psi
83	Propane 3.3% CF_3I 3.2%	3.34	3.23	0.018	0.3
84	Propane 3.3% CF_3I 3%	3.34	3.01	0.209	3.0

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RECENT WORK

"New" Agents | Blends of Agents

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NEW AGENTS & BLENDS EVALUATED

43L Sphere is a rapid screening tool

- Since 2019 over 300 inerting tests have been carried out(!)
- Single agents
  - HCFO-1224yd
  - 2-BTP
- Binary blends
  - HFO1224yd/CF_3I
  - HFO1224yd/CO_2
  - CF_3I/BTP
  - CF_3I/CO_2
- Ternary blends – still work in progress – three agents means many more combinations to test!
  - $CF_3I/BTP/CO_2$ and CF_3I/HFO1224yd/CO_2

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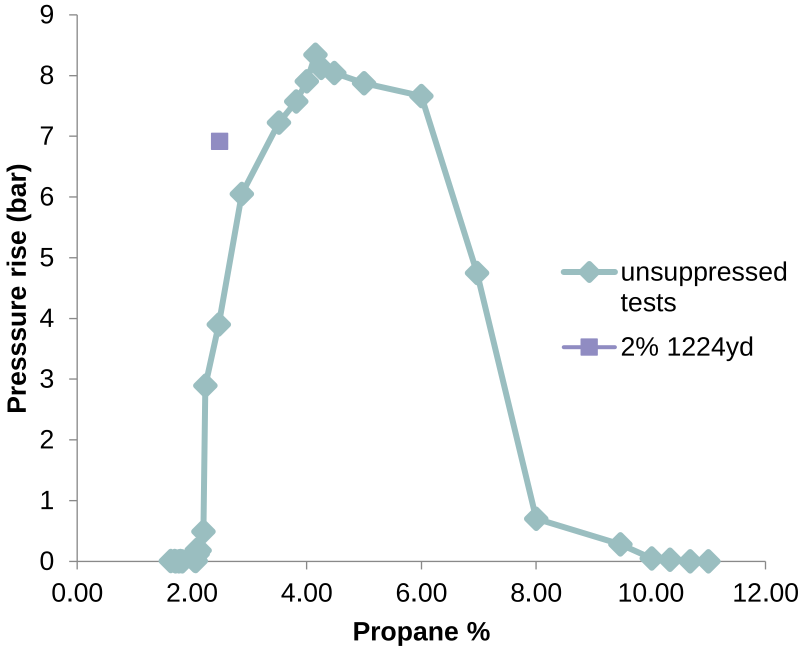
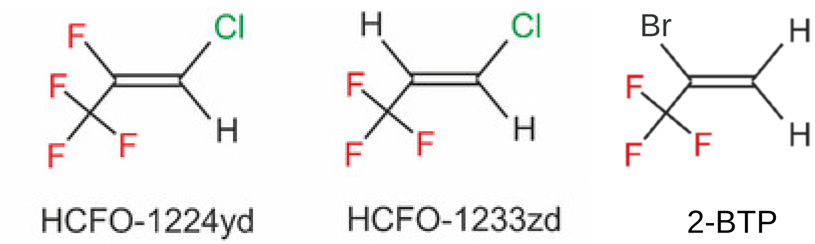
EXAMPLE OF A SINGLE AGENT:HFO-1224YD

43L Sphere Results

- Peak Inerting concentration is 8.8%
- Enhance explosion @ 2% 1224 yd



Propane (Vol%)	1224yd (Vol%)	Pressure (psig)
4	8.77	0.29
4.01	8.7	2.26



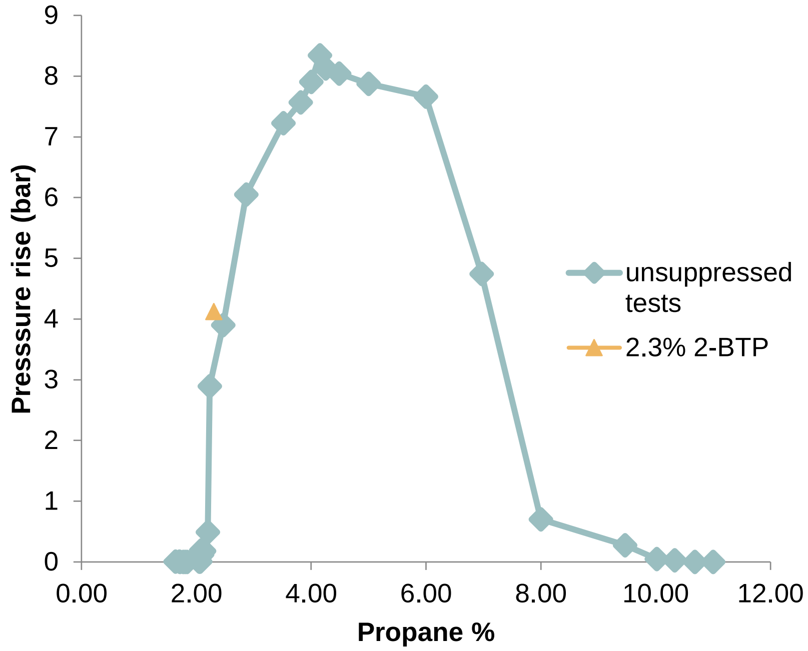
Boiling point: 15 °C 19 °C 34 °C

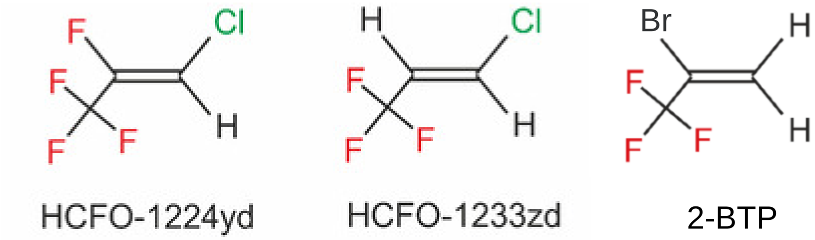
EXAMPLE OF A SINGLE AGENT:2-BTP

43L Sphere Results

- Peak Inerting concentration is 8.5%
- Enhance explosion @ 2.3% 2-BTP

Propane (Vol%)	1224yd (Vol%)	Pressure (psig)
2.3	3.25	59.83





Boiling point: 15 °C 19 °C 34 °C

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HFO-1224YD BLENDS

1. Blends with CF3I

Question 1:

- Minimum ratio of CF_3I to HCFO-1224yd to prevent enhanced explosion is 5:4.

Propane (Vol%)	CF3I (Vol%)	1224yd (Vol%)	CF3I:1224 (mol)	FIC	Pressure (psig)
2.51	2.12	0.69	3:1	0.4	**0.42**
2.54	2.43	1.15	2:1	0.5	**0.5**
2.51	1.98	1.61	5:4	0.49	**0.33**
2.64	1.98	2.01	1:1	0.53	**75.56**

Question 2:

- 3.64% CF_3I/2.87% 1224yd is lowest quantity that passed inerting test at that ratio

Propane (Vol%)	CF3I (Vol%)	1224yd (Vol%)	CF3I:1224 (mol)	FIC	Pressure (psig)
4	4.36	2.18	2:1	0.92	**0.46**
3.98	3.64	2.87	5:4	0.89	**0.95**

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HFO-1224YD BLENDS

2. Blends with CO_2

Question 1:

- What is the minimum ratio of CO_2 to HFO-1224yd that can prevent enhancement of pressure rise?
- We tried various ratios up to 5:1 CO_2:HFO-1224yd, but all failed
- CO_2 is not a “good enough” suppressant to overcome the fuel-like behaviour of this HFO, and testing was discontinued.

Propane (Vol%)	1224yd (Vol%)	CO2 (Vol%)	1224:CO2 (mol)	FIC	Pressure (psig)
2.48					**56.7**
2.5	1.98	2	1:1	0.3	**85.8**
2.51	1.61	3.21	1:2	0.3	**84.8**
2.57	1.54	4.54	1:3	0.34	**78.7**
2.5	1.53	5.93	1:4	0.39	**76.9**
2.5	1.17	6.01	1:5	0.35	**72.9**

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2-BTP BLENDS

Blends with CF_3I

Question 1:

- Minimum ratio of CF_3I to 2-BTP to prevent enhanced explosion is 1:3.

Propane (Vol%)	CF_3I (Vol%)	2-BTP (Vol%)	CF_3I:2-BTP (mol)	FIC	Pressure (psig)
2.48					56.74
2.49	0.92	2.71	1:3	0.46	1.57
2.49	0.67	2.84	1:4	0.44	75.33

Question 2:

- Minimum pass concentration of CF_3I/2-BTP at different ratios
- Synergy of CF_3I/2-BTP is not significant

Propane (Vol%)	CF_3I (Vol%)	2-BTP (Vol%)	CF_3I:2-BTP (mol)	FIC	Pressure (psig)
4.02	1.86	5.73	1:3	0.96	0.02
3.96	2.52	5.01	1:2	0.98	0.02
4	3.68	3.87	1:1	1.02	0.47
4.03	4.98	2.52	2:1	1.06	0.05
4.01	6	1.97	3:1	1.15	0.03

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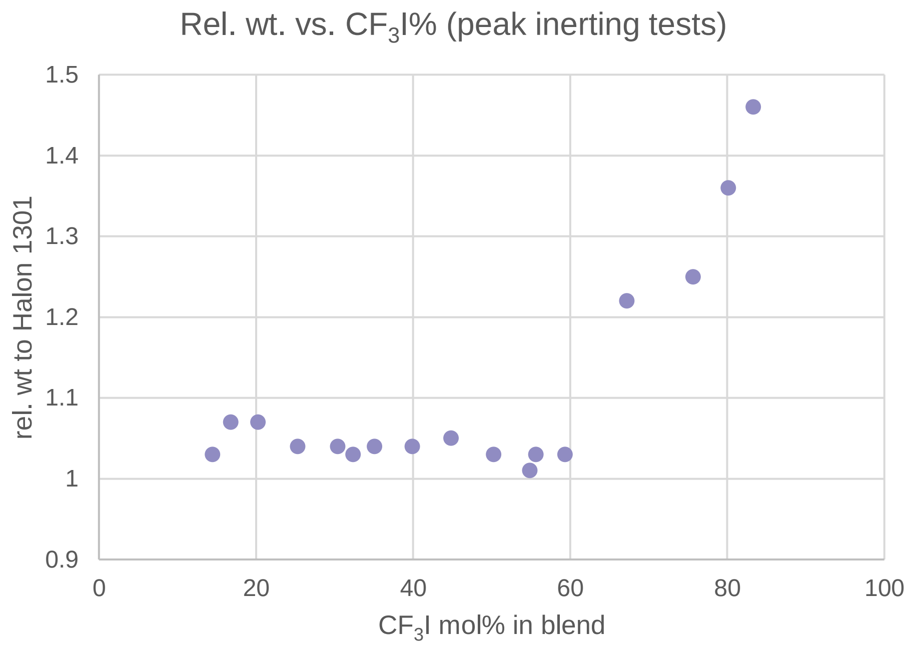
BLENDS OF CF_3I AND CO_2

Test results and conclusions

- From the full-scale testing carried out in 2019, we know that CF_3I exhibits lower thermal stability than Halon 1301
- So is there an opportunity to mitigate this using CO_2 as a cooling agent?
- Neither of these agents causes enhances combustion at lean propane-air ratios, so we are not constrained in our choice of ratio
- Up to ~60% CF_3I, good performance is obtained, illustrating synergy between physically- and chemically-acting agents



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SUMMARY OF RECENT WORK

- Inerting tests completed in the 43L sphere (single agent)
  - Both 2-BTP and HFO1224yd function as a fuel at sub-inerting concentrations
  - In line with expectations
- Inerting tests completed in the 43L sphere (blends)
  - Achieved inerting at a range of mixtures of CF_3I/2-BTP, CF_3I/CO_2, CF_3I/HFO-1224yd
  - No blends of HFO-1224yd/CO_2 were identified that did not enhance combustion of lean propane / air
    - Best ratio for CF_3I/2-BTP blend is around 1:2 by mol
    - Best ratio for CF_3I/CO_2 blend is between 1:3 and 1:1 by mol

CONCLUSIONS

- Testing agents at fuel–lean stoichiometry in the 43 L Sphere mimics behaviour in the full scale FAA ACT
  - Several (all?) agents that have failed full scale ACT also exhibit enhanced explosion in 43L sphere
  - This pre-test is being added to the revised Cargo Compartment MPS
- Testing at intermediate propane air concentrations offers a screening test to define likely pass/fail criteria for the full scale aerosol can test
  - CF_3I at 3.2% was capable of passing the Aerosol Can Test
- Blends of stable and less-stable agents can be created that can control the ACT

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ACKNOWLEDGEMENTS

- Coworkers at Kidde
  - Josephine Gatsonides – set up the original test at Kidde Research in the UK
  - Terry Simpson and Eli Baldwin – helpful discussions and suggestions for blends
  - Bob Royer, Jerry Jackson – the technicians who actually carried out the tests
- Coworkers at Raytheon Technologies Research Center
  - Paul Papas – helpful discussions, modelling

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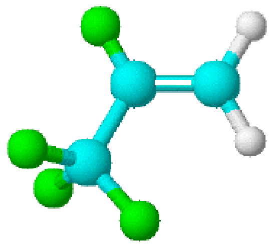
BACK UP

REFRIGERANT NUMBERING EXPLAINED

Hydro-Fluoro-Olefin 2,3,3,3-tetrafluoroprop-1-ene



HFO – 1 2 3 4 y f

Also HCFO: Hydro-Chloro-Fluoro-Olefin

- 1: # of unsaturated bonds
- 2: # of carbon atoms - 1
- 3: # of hydrogen atoms + 1
- 4: # of fluorine atoms

Propene Series

- y: Substitution on central carbon: x: -Cl, y: -F, z: -H
- f: Substitution on terminal methylene carbon:

a: $=CCl_2$	b: $=CClF$
c: $=CF_2$	d: $=CHCl$
e: $=CHF$	f: $=CH_2$

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