Federal Aviation Administration

Extinguishing Agents Against Lithium Battery Gases

Presented to: Spring 2021 Systems Meeting

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Background/Motivation

- **Replacement of Halon within cargo compartments.**
  - European Commission cutoff date for new type certificate applications for aircraft was in 2018.
- **Previously, experiments had been performed to look at the effectiveness of Halon 1301 against lithium battery gases.**
- **Lithium battery fires are becoming more common**
- **As new extinguishing agents become available, it is important to know how effective the agents are against lithium battery fires.**

Background – Battery Fires

- **The main source of fuel for lithium battery fires is generally the flammable gases generated from thermal runaway.**
  - Flammable battery gas composition can vary due to many factors including State-of-Charge, Chemistry, and overall design.
  - Three main flammable gases:
    - Hydrogen
    - Hydrocarbons
    - Carbon Monoxide
  - Among the 3 gases, composition variations can seem endless, especially due to the broad variety of hydrocarbons that can exist.

Objective

- **Develop a method of evaluating the effectiveness of cargo compartment fire suppression agents against lithium battery fires.**

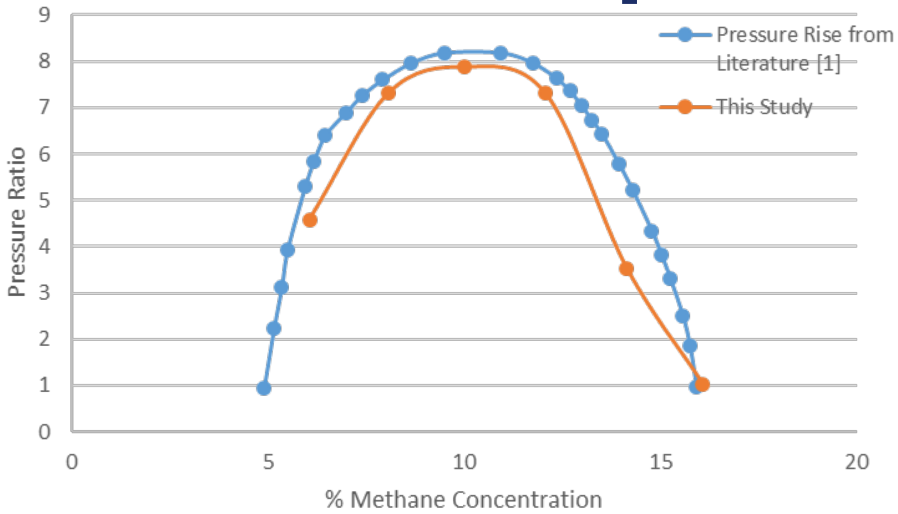
Test Plan

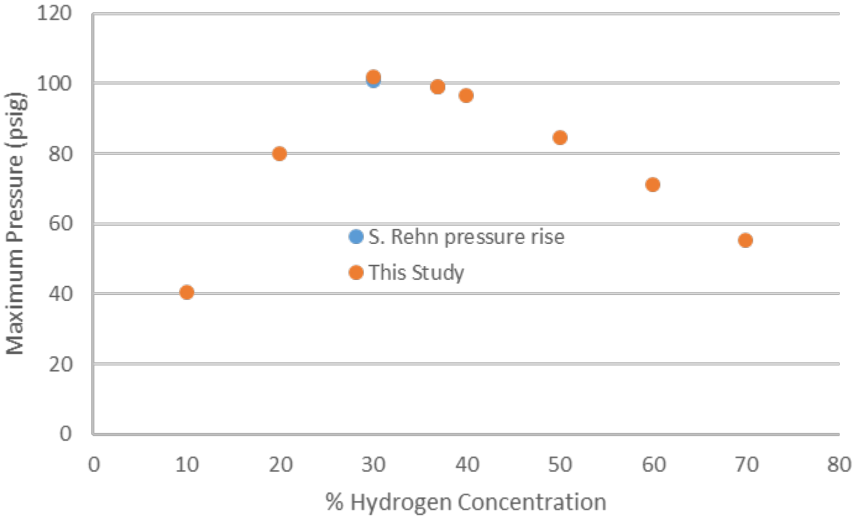
- Initial tests
  - Verify setup and provide some understanding of the interaction between flammable gasses and agents.
- Flammability limit tests Tests
  - Use chemical kinetics simulations to get an idea of the behavior of various battery gas combinations against fire extinguishing agents.
    - Halon 1301
    - BTP/CO_2 mix
    - CO_2
  - Use pressure vessel experiments to validate/understand the various predicted simulation results.
    - Agents
      - » Halon 1301
      - » BTP/CO_2 mix
      - » CO_2
    - Flammable Gasses
      - » Hydrogen
      - » Methane
      - » Ethylene
      - » CO

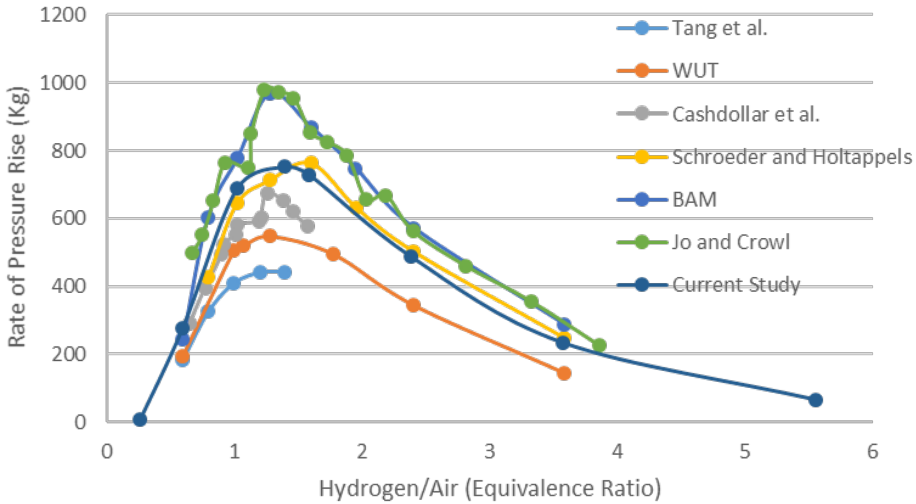
Setup

- **Simulations: Chemkin & Cantera (provide identical results)**
  - Use mechanism files that were compiled previously by NIST
  - Use laminar flame speed as a predictor of flammability
- **Experiments:**
  - 21.7 liter combustion sphere
  - Spark igniter for ignition (0.5 second duration, 10k volts, 5mm gap)
  - Small computer fan to mix gasses
  - Piezo-electric pressure sensor (max pressure and max rate-of-pressure rise)

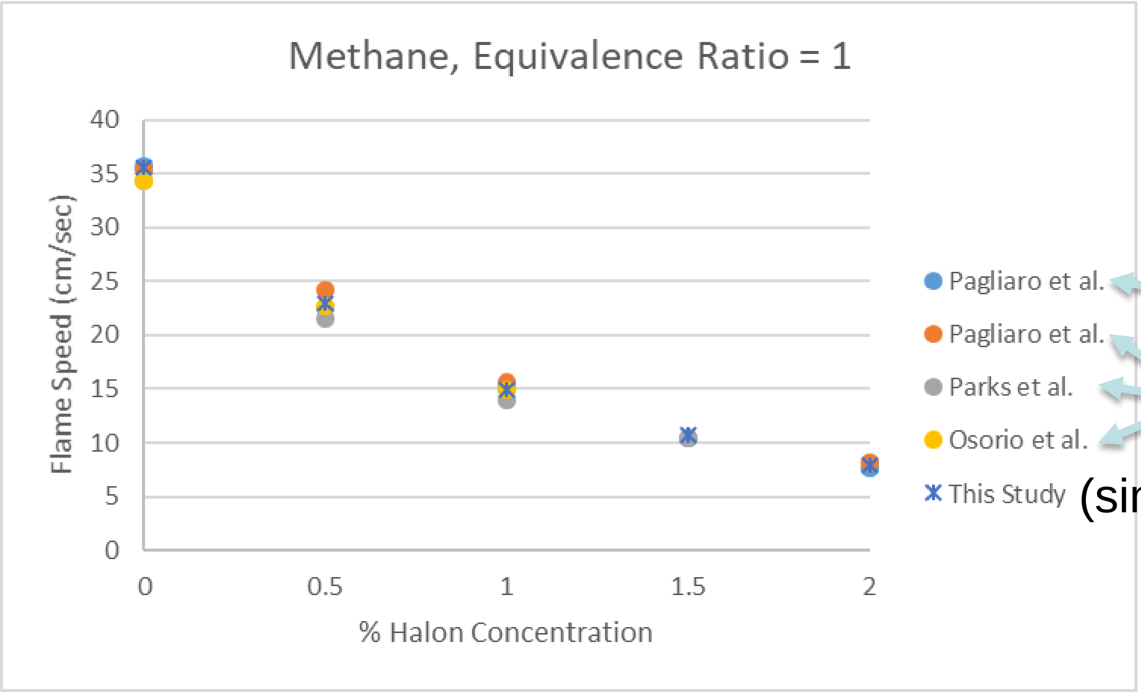
Results-experimental validation







Results-simulation validation

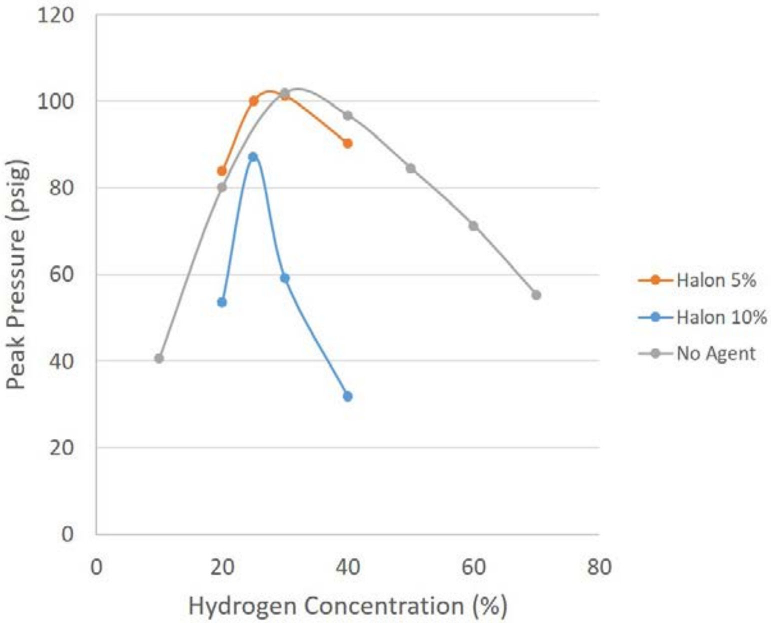


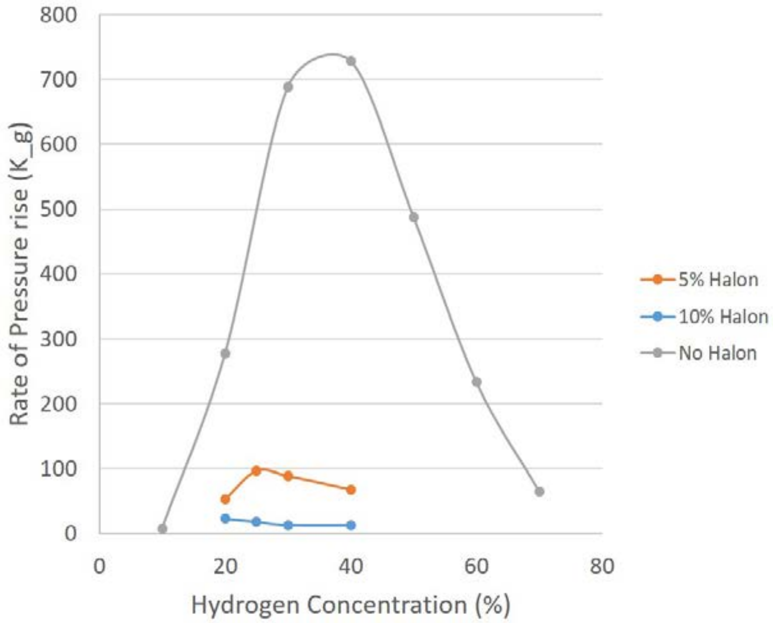
Simulation results

Experimental results

(simulation)

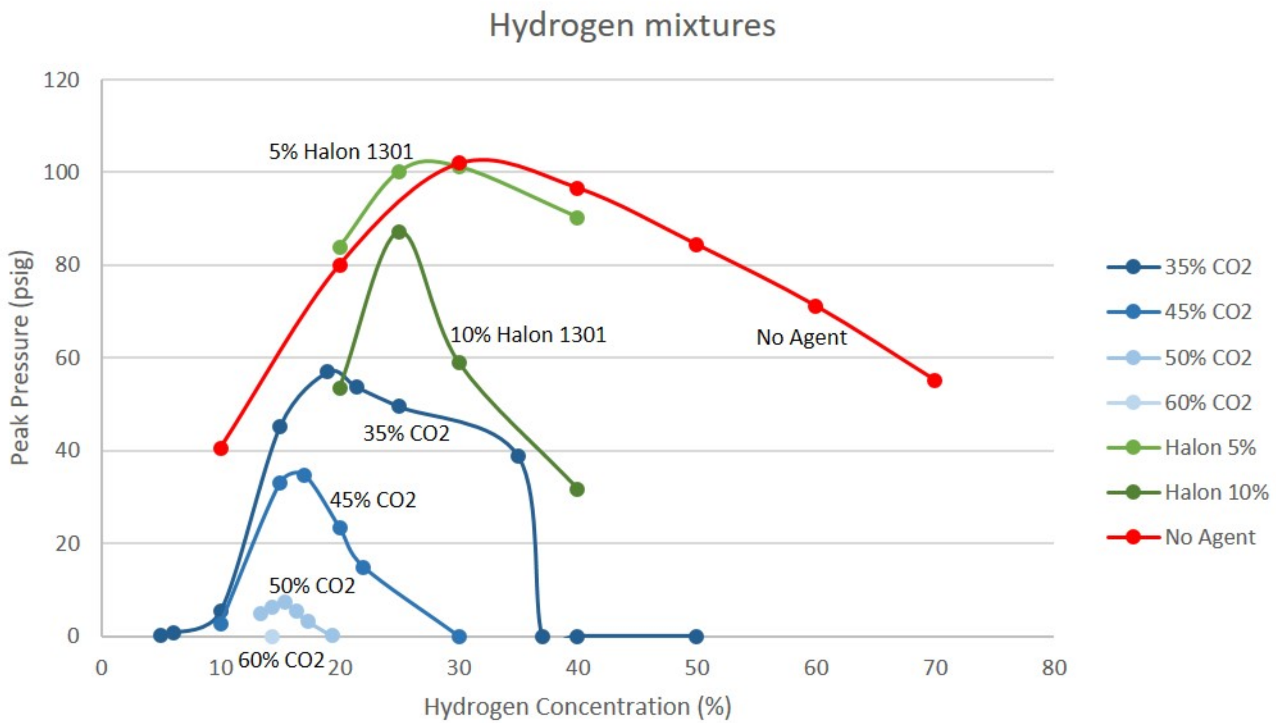
Initial testing – Halon and Hydrogen





- Lower concentrations of Halon 1301 can have little effect on peak pressure but significantly reduce rate of pressure rise.
- Correlates to a significant decrease in flame speed but a much less significant decrease in total heat release.

Initial testing – flammability curves

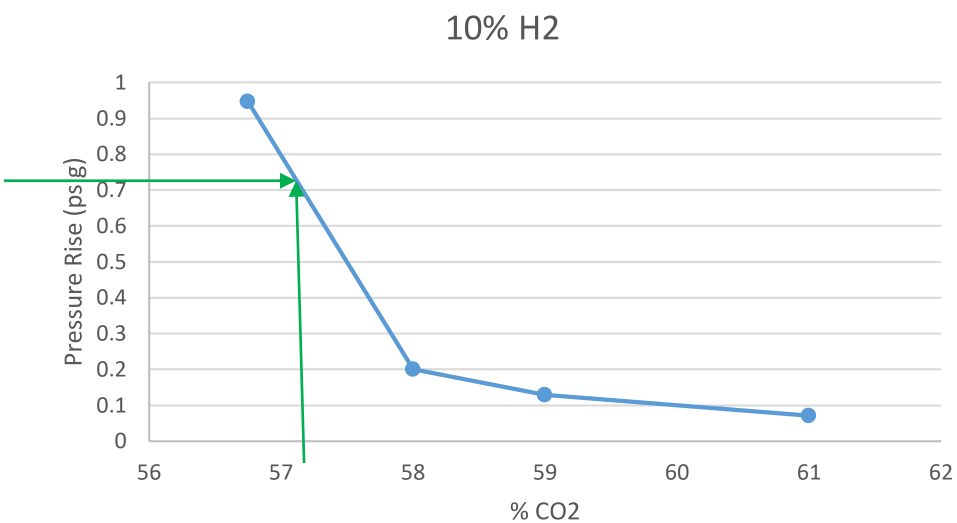


- Certain halon/hydrogen mixtures have a greater pressure rise than if no halon was added.

LFL testing

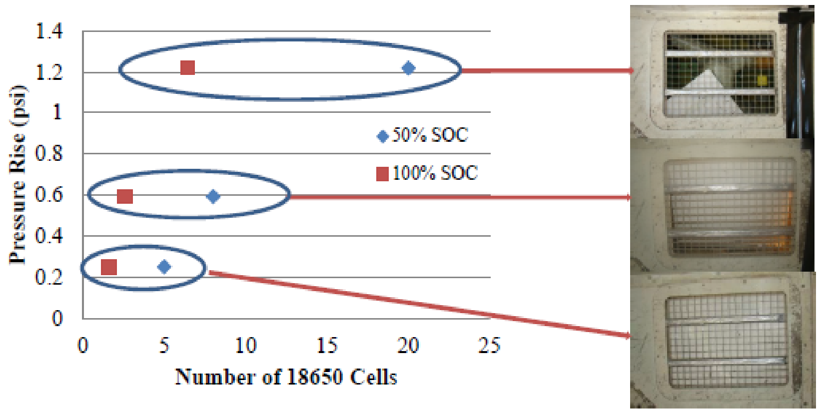
- **5% pressure rise criteria**
  - 0.735psi at sea level
  - About the pressure required to dislodge a cargo compartment decompression panel.

Example:



Interpolation to find values

Recall from previous work:



Laminar Flame Speed

- **Often times used as a "gauge" for determining whether a mixture is flammable or not.**
- **If flame speed is too low, flame cannot propagate and becomes extinct.**
- **Extinguishing flame speed varies with several parameters such as ignition energy and initial temperature**
  - Generally between 2 cm/sec and 5 cm/sec

Methane and CO2

phi=1

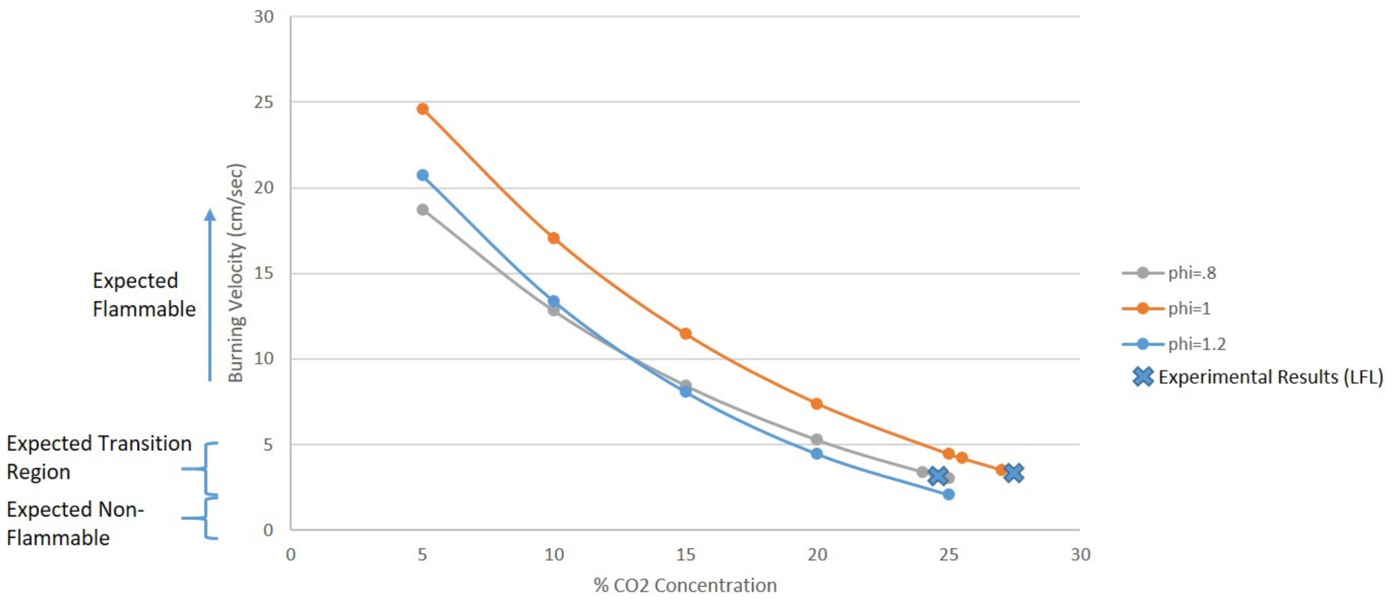
% CO2	burning velocity	% CH4	pressure rise (psig)
5	24.638		
10	17.066		
15	11.476	8.1	
20	7.406	7.6	
25	4.455	7.1	6.53
25.5	4.204	7.1	5.93
27	3.533	6.9	1.527
27.5	3.32	6.9	0.426

← LFL (at 27)

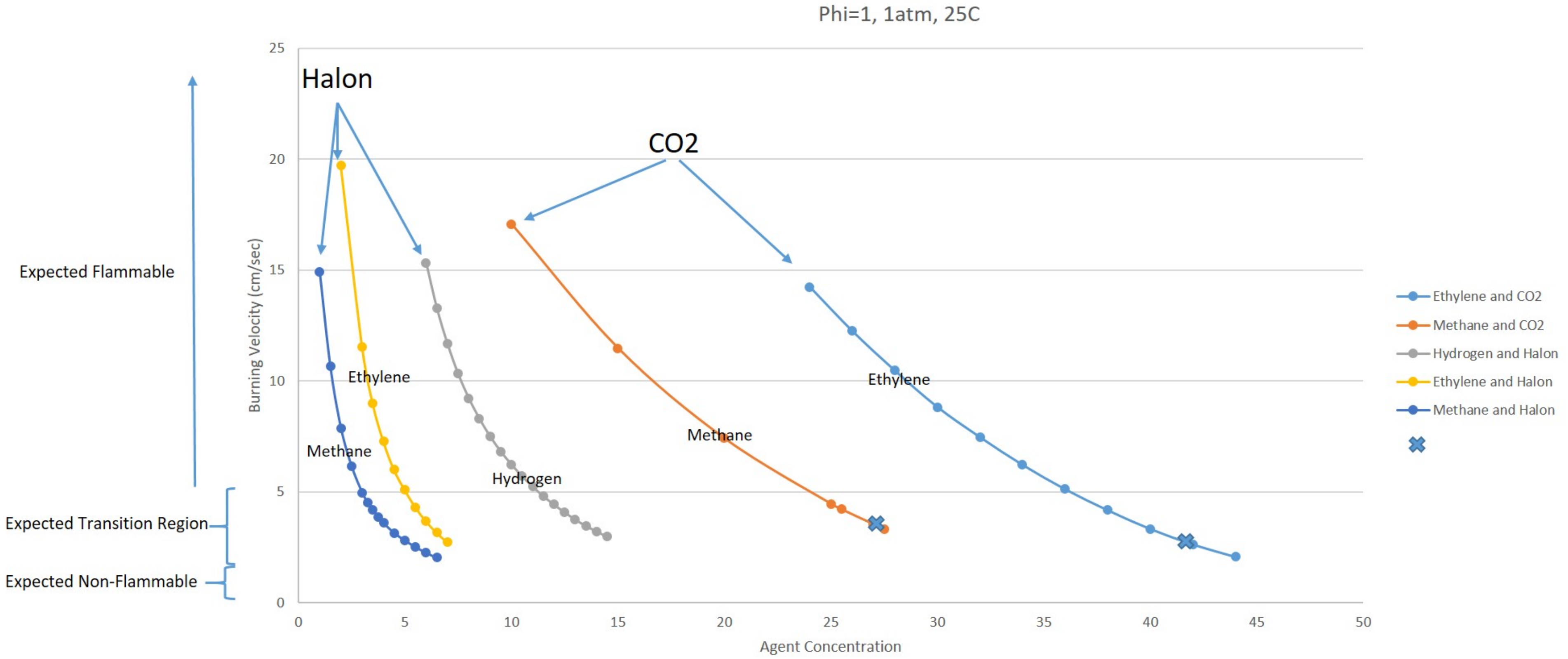
phi=.8

% CO2	burning velocity	% CH4	pressure rise (psig)
0	26.799	7.7	
5	18.757	7.4	
10	12.823	7	
15	8.464	6.6	
20	5.29	6.2	
24	3.419	5.9	1.766
24.5	3.223	5.9	1.7457
25	3.036	5.8	0.537

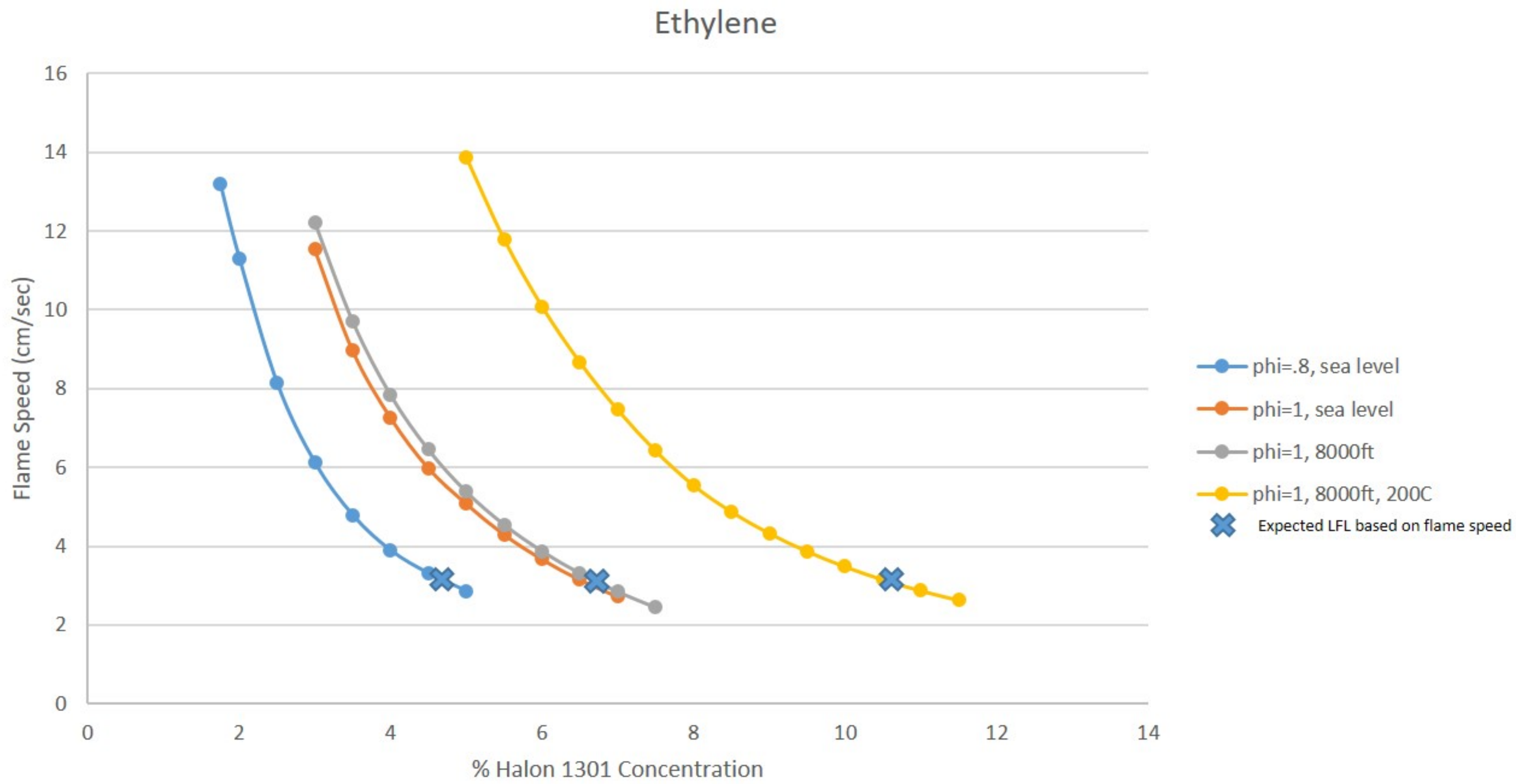
← LFL (at 24.5)



Comparison of gases



Altitude/elevated temperature effect



- Extinguishing agents are predicted to be much less effective at elevated temperatures
- Extinguishing agents effectiveness show little variability with altitude

Summary

- The greatest quantity of extinguishing agent is required at or near equivalence ratio of 1.
- Not all hydrocarbons behave the same. For example, ethylene appears to require more halon and more CO2 than methane.
- Hydrogen requires the most agent out of all flammable gasses evaluated so far.
- Extinguishing agents are far less effective at elevated temperatures. (A suppressed/smoldering cargo compartment will have elevated CO2, so results may be mixed.)

Future Work

- **Continue running experiments to fill in test matrix**
  - Mixtures of flammable gasses (actual battery gasses)
  - All individual gasses at phi=1 and phi=.8 with all extinguishing agents.
- **Run simulations on other flammable gasses (other than the 4 listed) to determine if they are worth running pressure tests on.**
- **Possibly look at aerosols and powders.**

Citation

- [1] Flammability of methane, propane, and hydrogen gases; Cashdollar, Zlochower, Green, et al.