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A Critical Review on the Suppression Mechanisms of Total-flooding Agents

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Outline

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- A thermal explanation of flammability diagram
- Extrapolations from ignition to extinction
- Screening fuel suppressibility using flammability limits
- Ranking agent suppression effectiveness using CB values
- The thermal view on the synergistic effect

The simplest fire suppression theory

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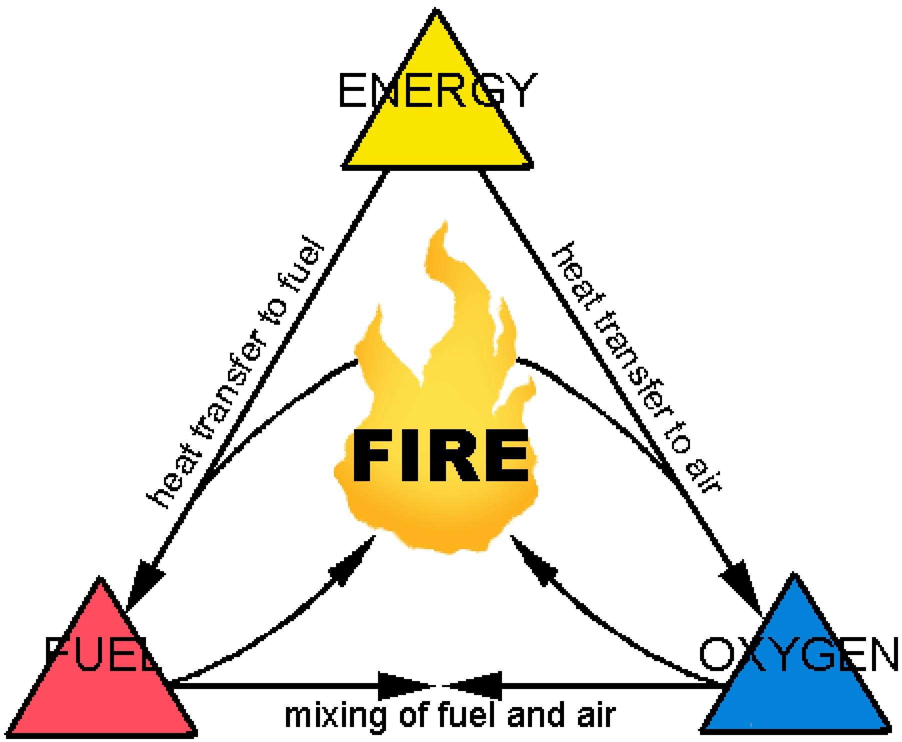
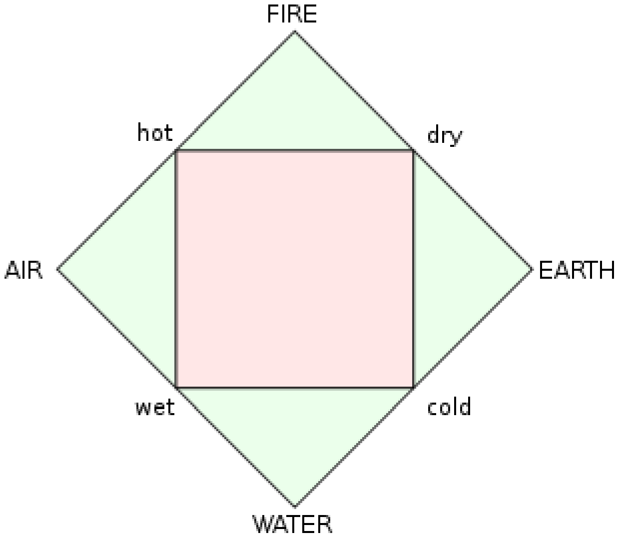
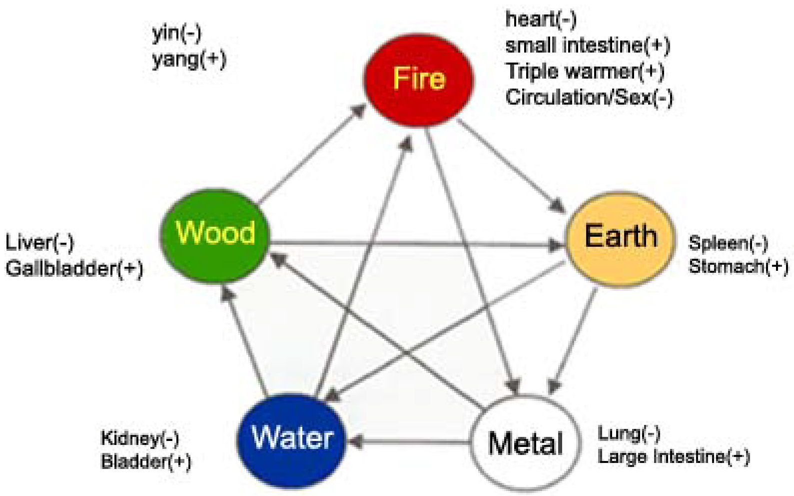
- Fire triangle







Overview of suppression mechanisms

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- Major mechanisms
  - Oxygen depletion
  - Heat absorption (specific heat)
  - Fuel removal
  - Chemical Inhibition/Synergistic effects
- Other effects
  - Radiative heat loss
  - Flow stretching
  - Wall-cooling

A universal theory is impossible

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- Heat and mass transfer → Spalding's B-number theory (Rasbash's fire point theory) + droplet dynamics
- Fluid mechanics & chemistry→ Damkoehler number theory
- Combustion/reaction → chemical equilibrium (Semenov theory)

Basic assumptions

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- The thermal process governing ignition is similar to the thermal process governing extinction.
- The major thermal mechanisms are
  - Quenching by mass
  - Flame temperature change
  - Lump-sum heat loss term (including velocity effect)

A closer look at flammability diagram of propane

$$C_aH_bO_c + C_O\cdot(O_2+3.773N_2)+C_d\cdot D \rightarrow a\cdot CO_2+0.5b\cdot H_2O+3.773a\cdot N_2+C_d\cdot D$$

$$C_O = a + b/4 - c/2$$

$$C_{st} = 1 + 4.773\cdot C_O$$

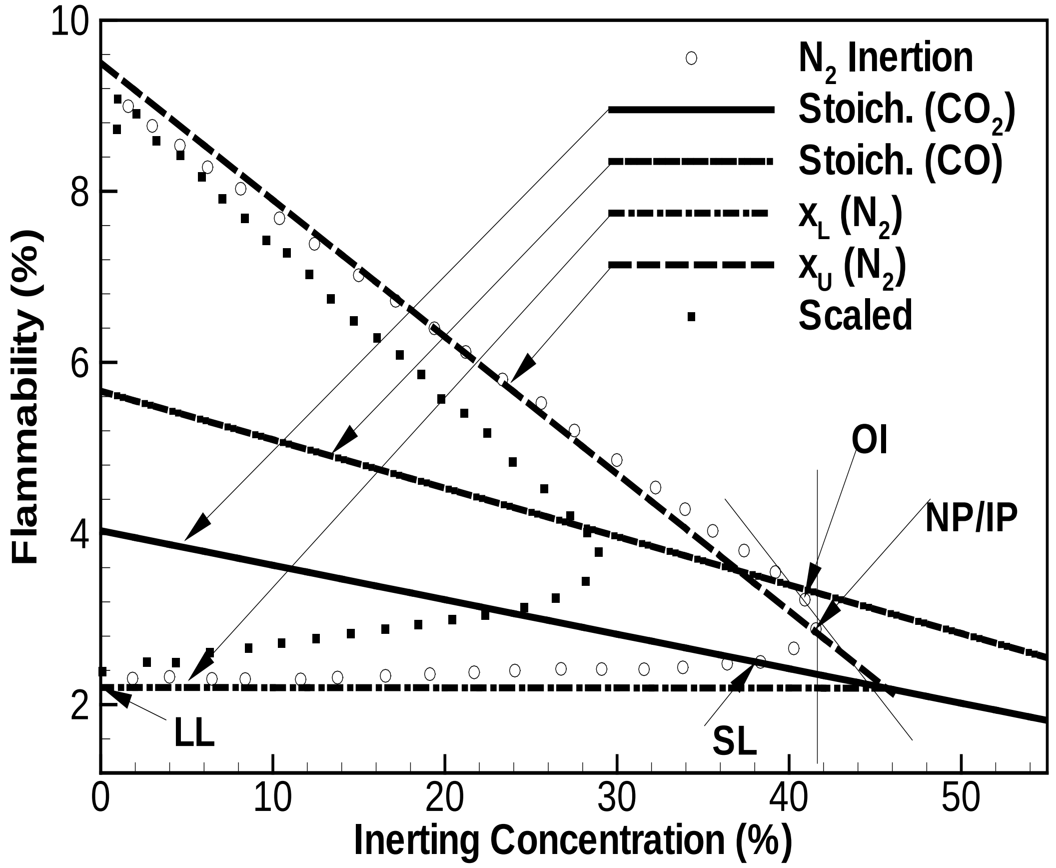
$$x_L = \frac{1-(1-Q_D)\cdot x_D}{1-Q_F+C_O\cdot H_O} = x_{L,0}\cdot\left[1-\left(1-Q_D\right)\cdot x_D\right]$$

$$x_U = x_{U,0} - (x_{U,0} + \frac{Q_D}{Q_F-1+H_O/4.773})\cdot x_D$$

$$x_{st} = \frac{1-x_D}{1+4.773\cdot C_O} = x_{st,0}(1-x_D)$$

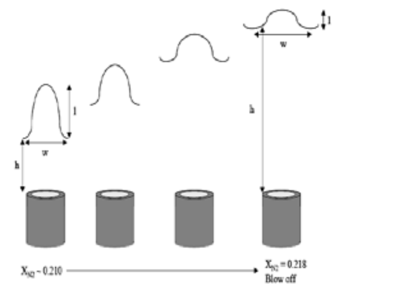
$$C_O = a/2 + b/4 - c/2$$

$$C_{st} = 1 + 4.773\cdot C_O$$

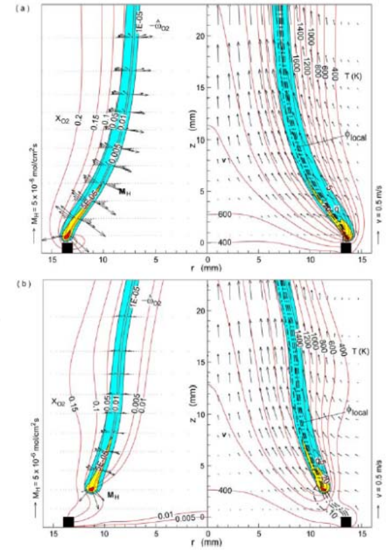


Cupburner test

- Inerting effect
- Reacting effect
- Wall Quenching Cooling effect
- Temperature effect
- Velocity effect



The evolution of the methane diffusion flame structure as additional N_2 is added to the coflow air stream is shown.



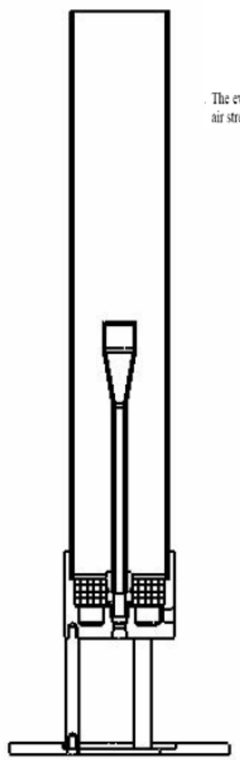


Figure A1. Cup-burner assembly.

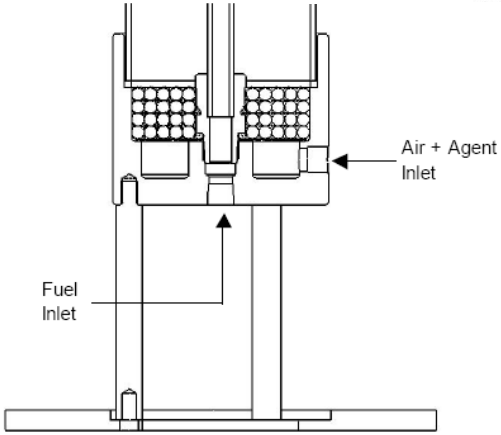


Figure A2. Base assembly, enlarged.

From ignition to inertion

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Step 1: $$X_{i,fuel} = LFL$$

Step 2: $$\nu_{i,air} = \frac{1 - C_{st} \cdot X_{i,fuel}}{X_{i,fuel}}$$

Step 3: $$\nu_{i,agent} = \frac{\nu_{i,air}}{\alpha \cdot \beta}$$

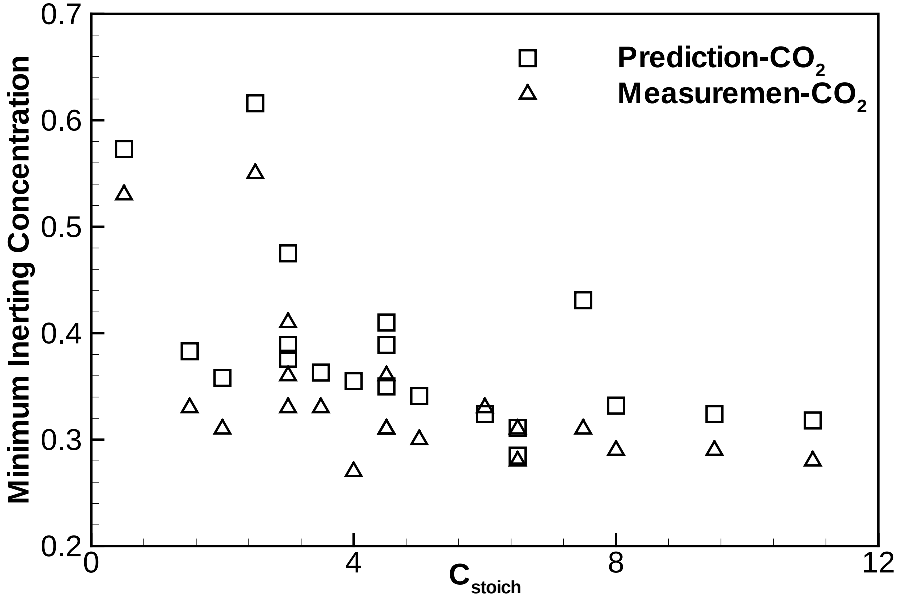
$$\alpha_i = \frac{\left(H^0_{AFT} - H^0_{298.15}\right)_i}{\left(H^0_{AFT} - H^0_{298.15}\right)_{air}}$$

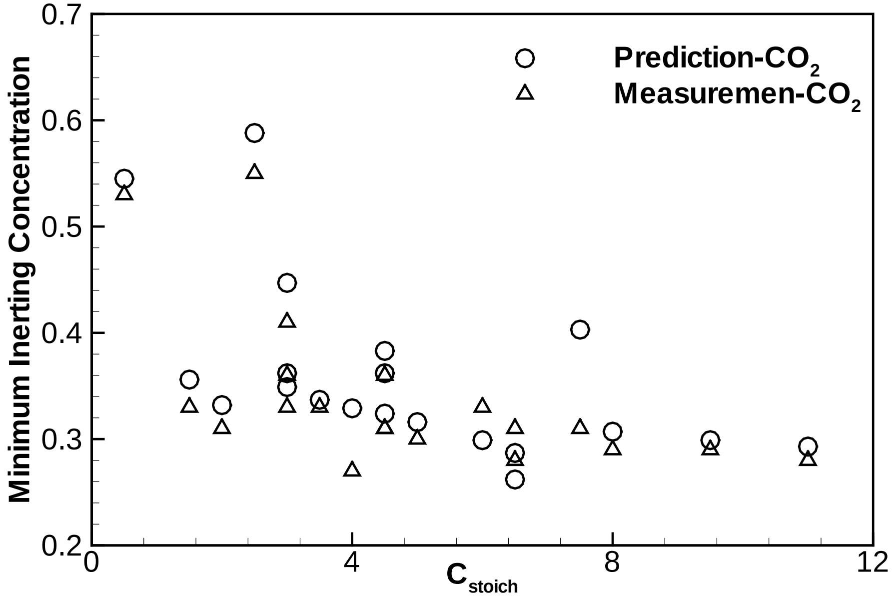
$$\beta_i = \frac{\left(T_{AFT}\right)_{extinction}}{\left(T_{AFT}\right)_{ignition}}$$

Step 4: $$X_{i,agent} = \frac{\nu_{i,agent}}{1 + \nu_{air} + \nu_{i,agent}}$$

MIC prediction w/o FT corrections

- *without temperature correction* ($\beta = 1$)
- *with temperature correction* ($\beta = 1.112$)





Cupburner test results

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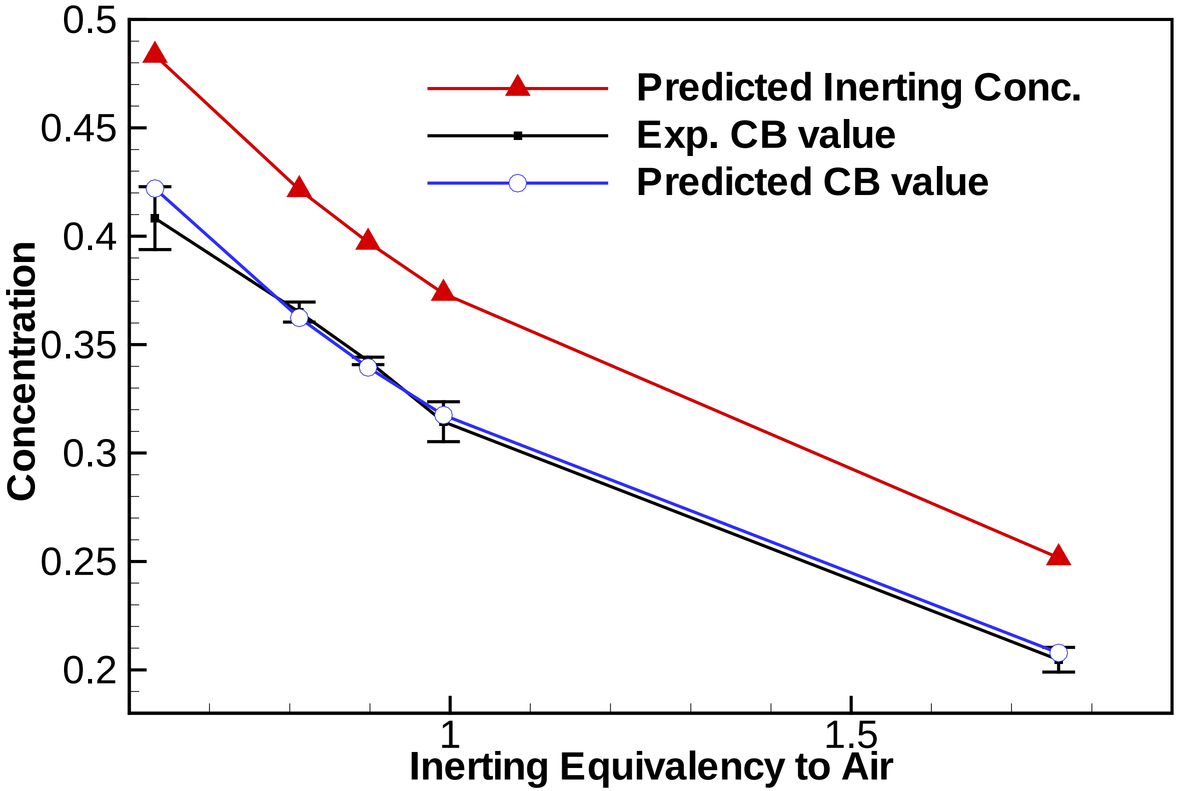
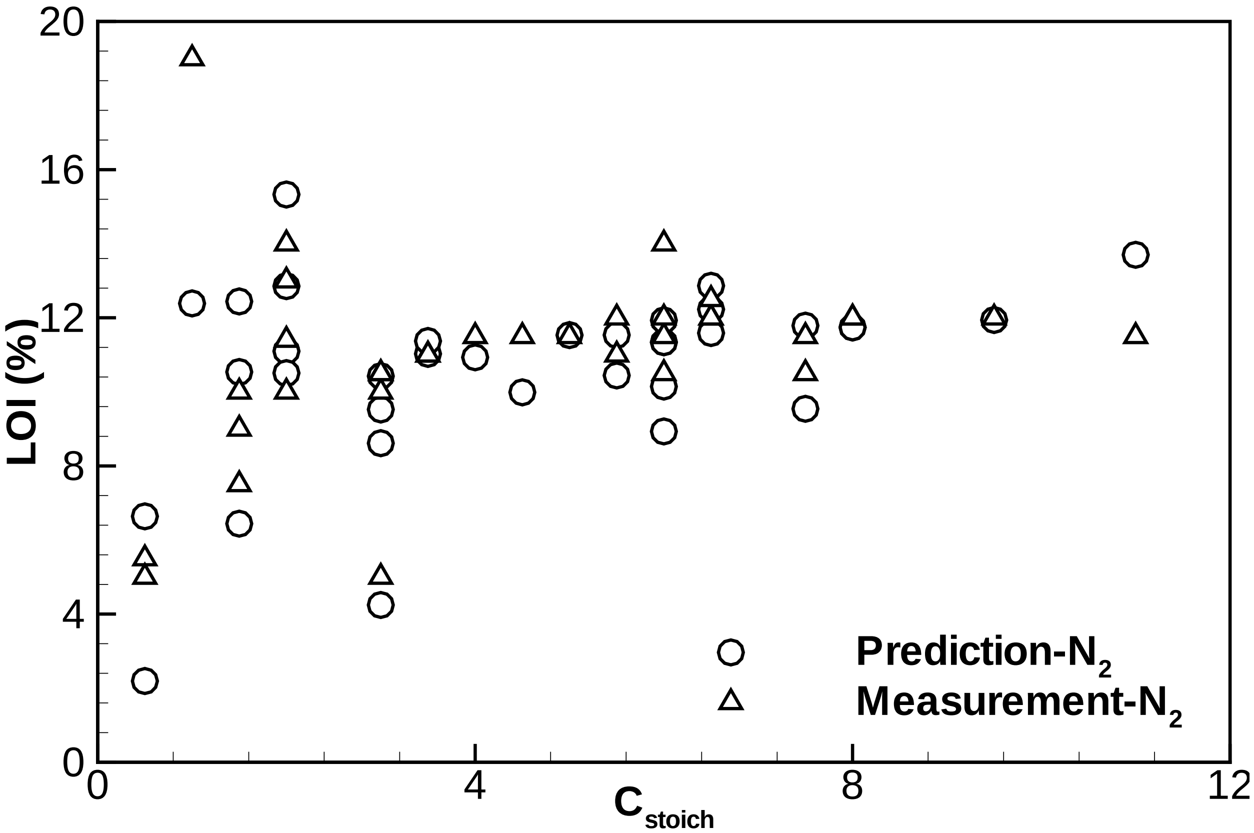
	Argon	Argonite	Inergen	Nitrogen	CO2
Quenching factor	0.632	0.812	0.898	0.992	1.615
Loss factor	1.282	1.282	1.282	1.282	1.282



LOC predictions under N_2 Inerting

- LOC estimation: $LOC = \left(1 - X_s - X_f\right) \cdot 0.209$



LOC predictions under CO_2 inerting

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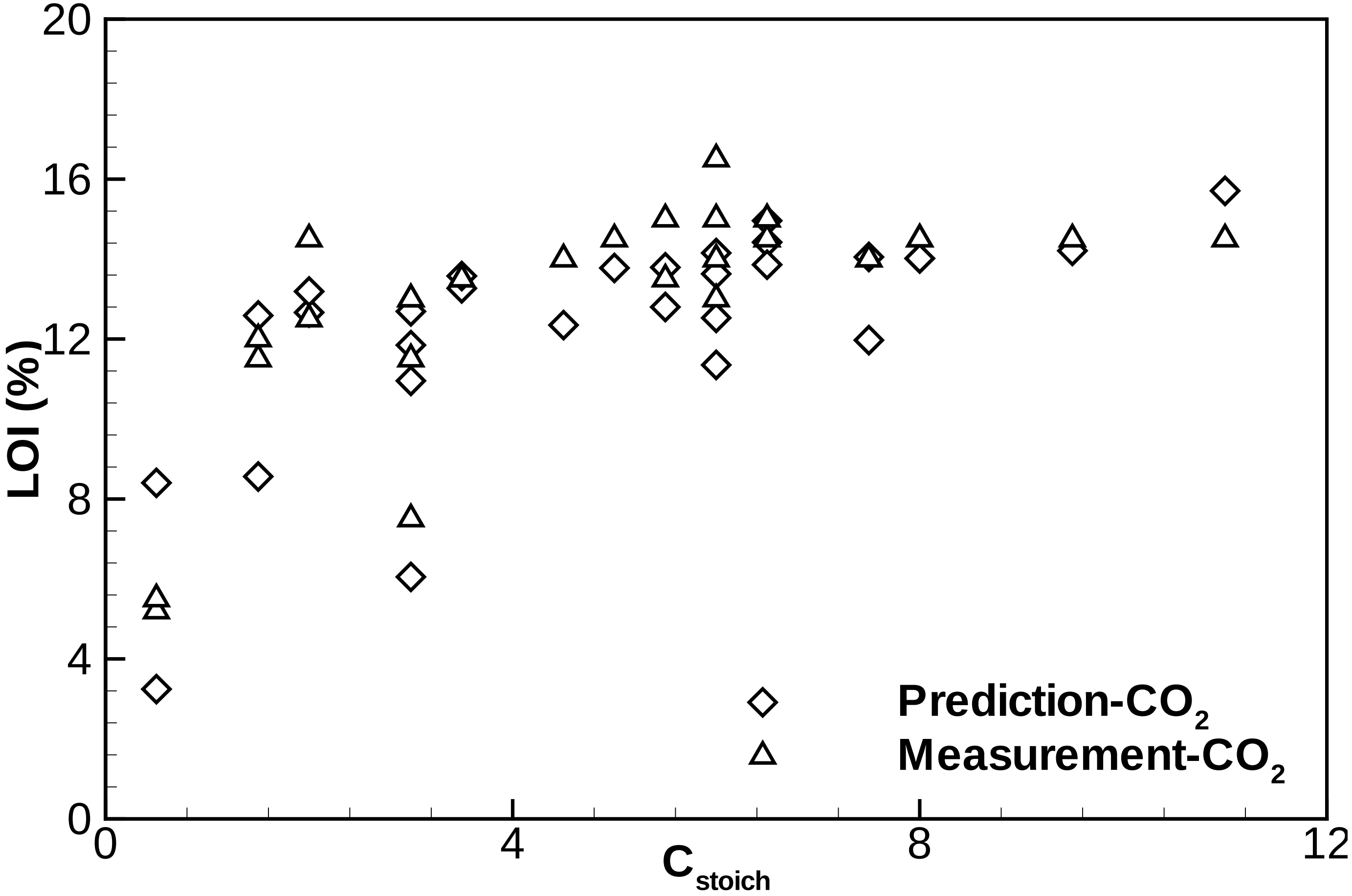
$$LOC = \left(1 - X_s - X_f\right) \cdot 0.209$$



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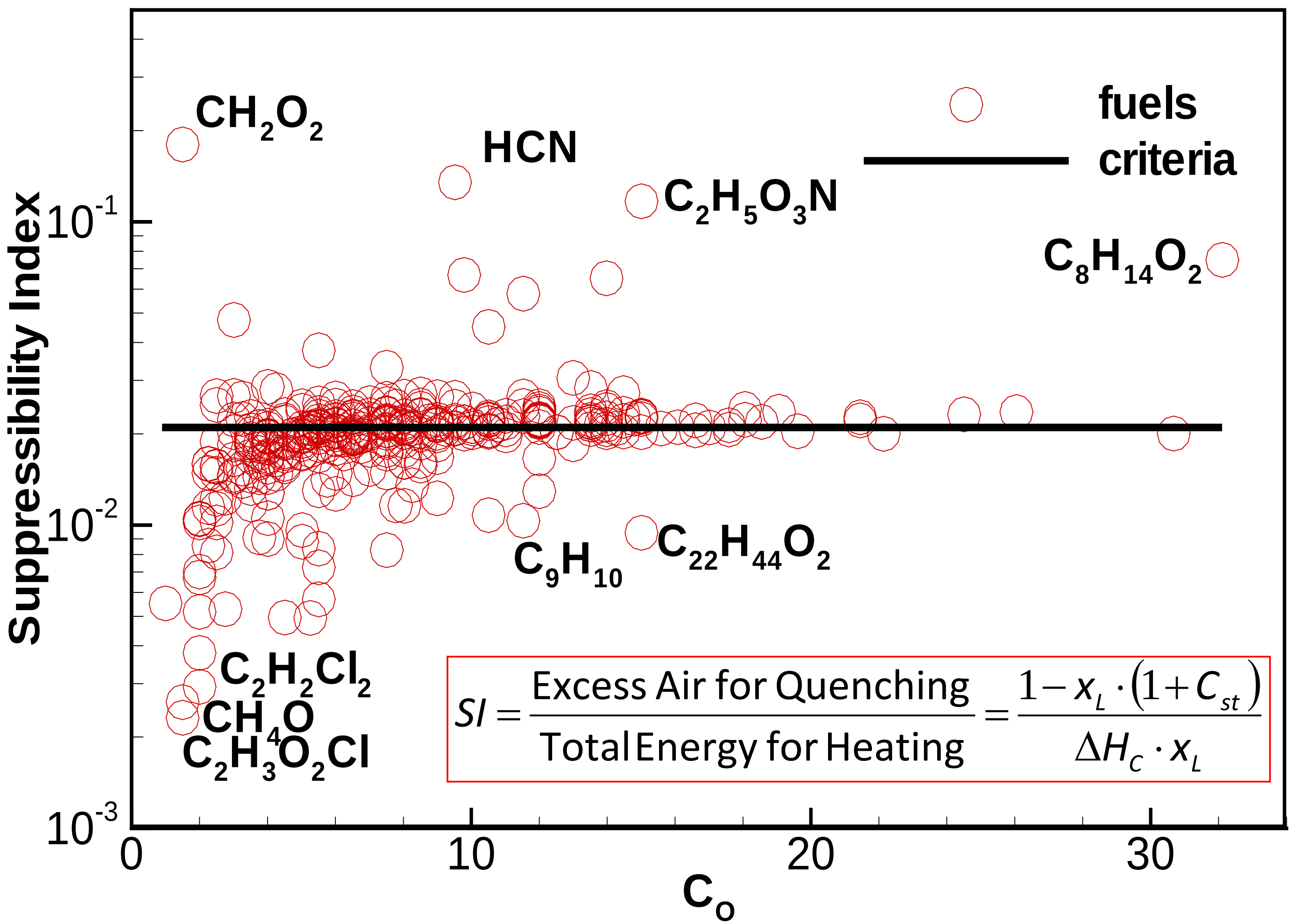
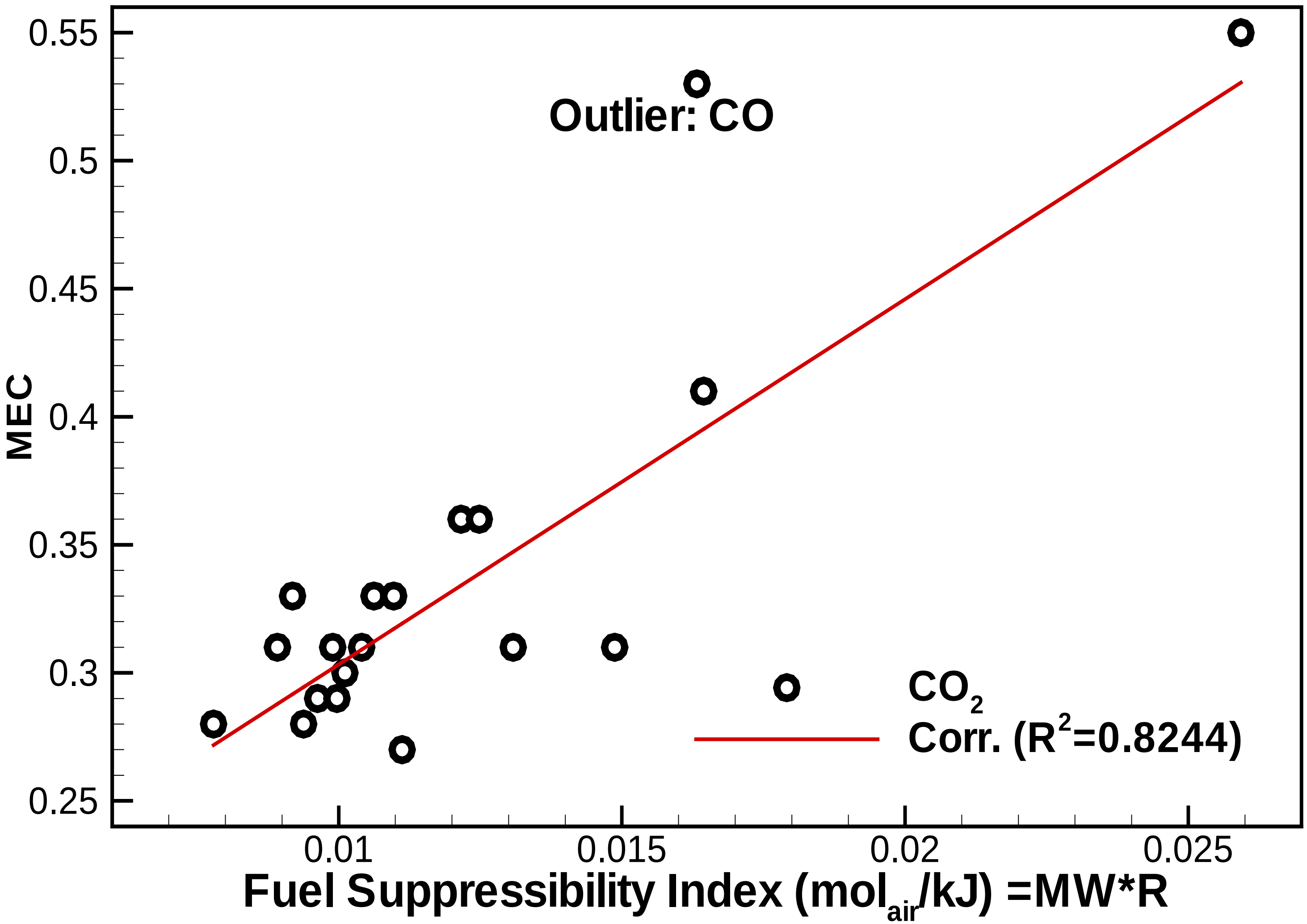
Screening of fuels by suppressibility



MEC vs. Fuel suppression index



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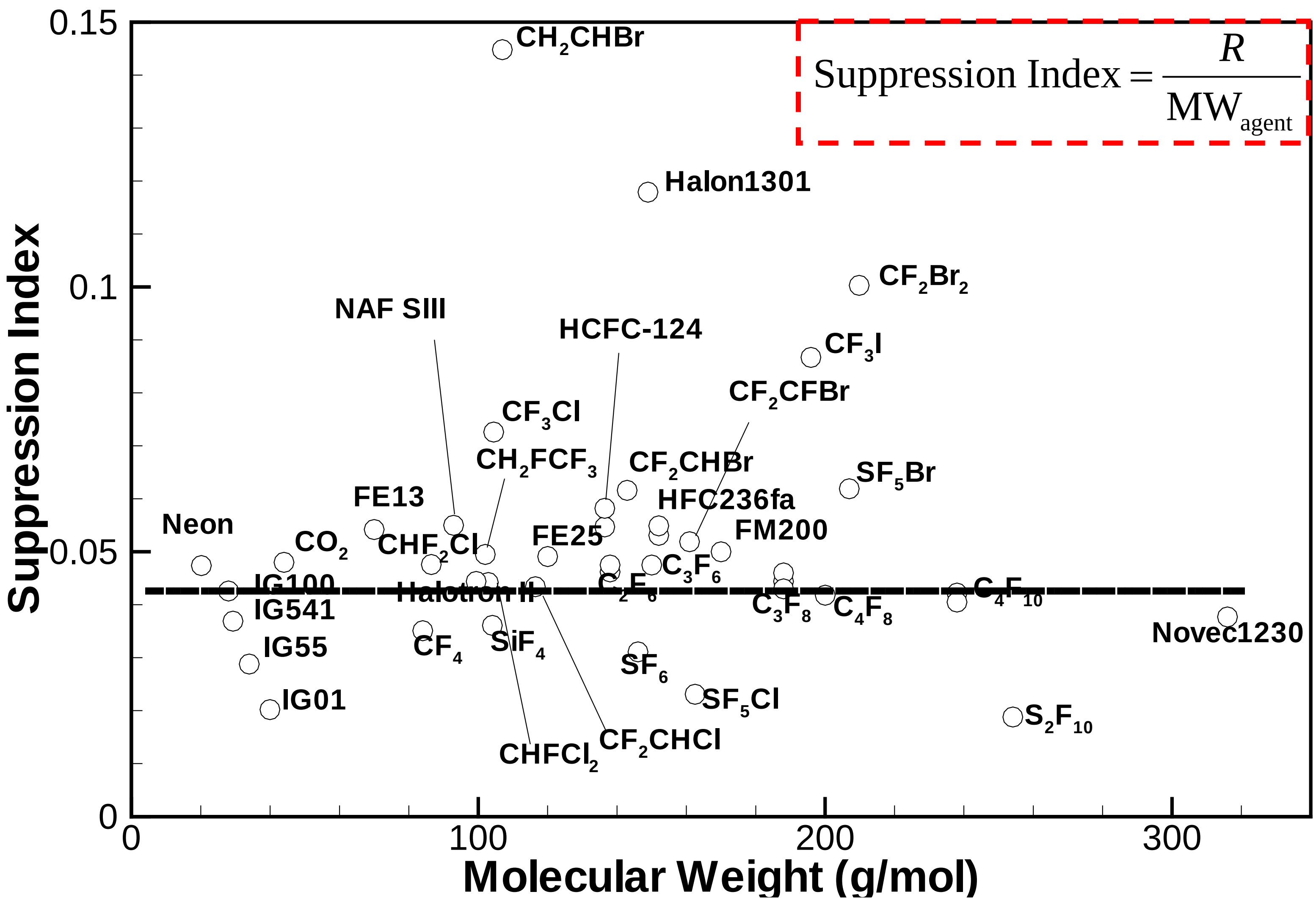
Screening of agents by effectiveness



$$\nu_{i,air} = \frac{1 - C_{st} \cdot x_L}{x_L}$$

$$\nu_{i,agent} = \frac{\nu_{i,air}}{R}$$

$$x_E = \frac{\nu_{i,agent}}{1 + \nu_{air} + \nu_{i,agent}}$$

$$R = \frac{1 - x_E}{x_E \cdot C_{st}} \cdot \left(\frac{1 - C_{st} \cdot x_L}{x_L} \right)$$

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Role of Halons

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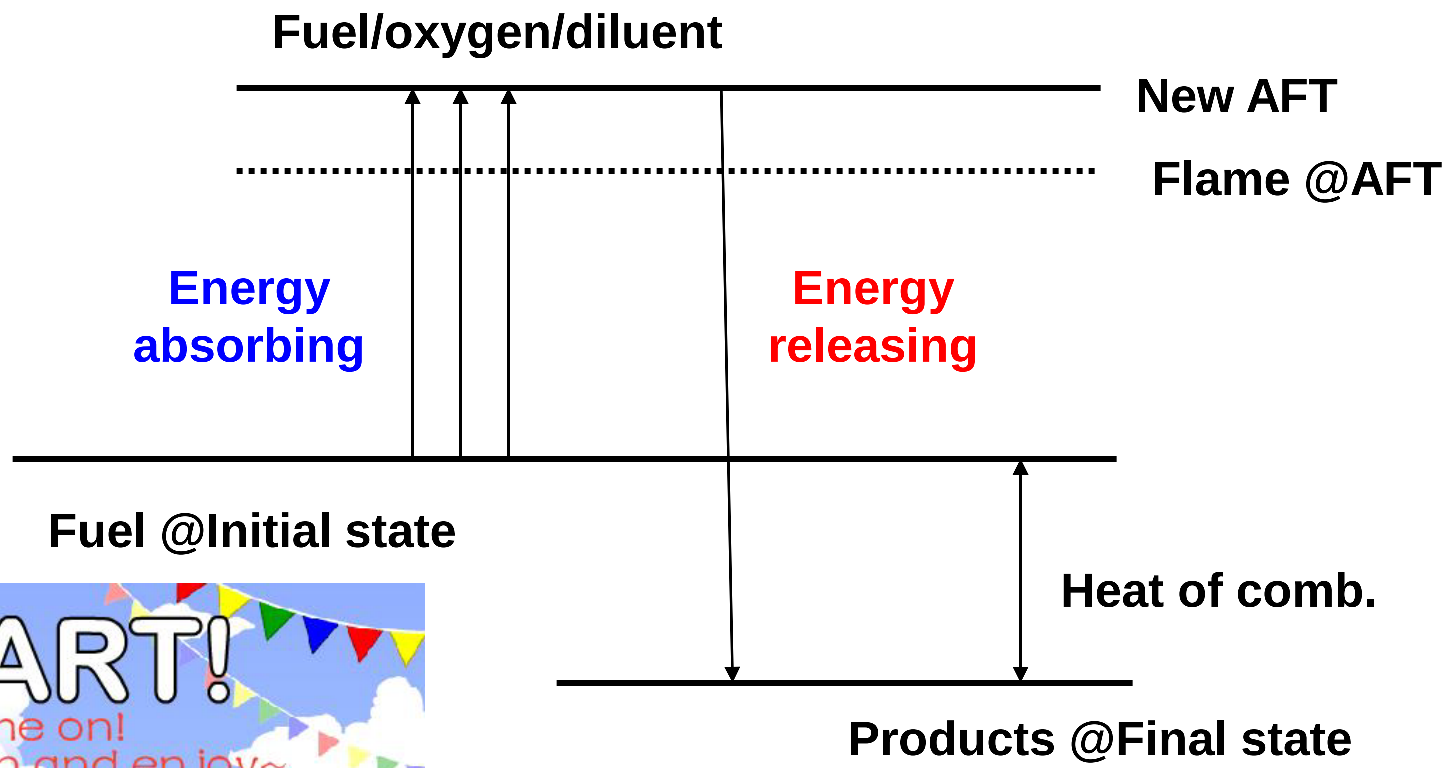

Synergistic Index

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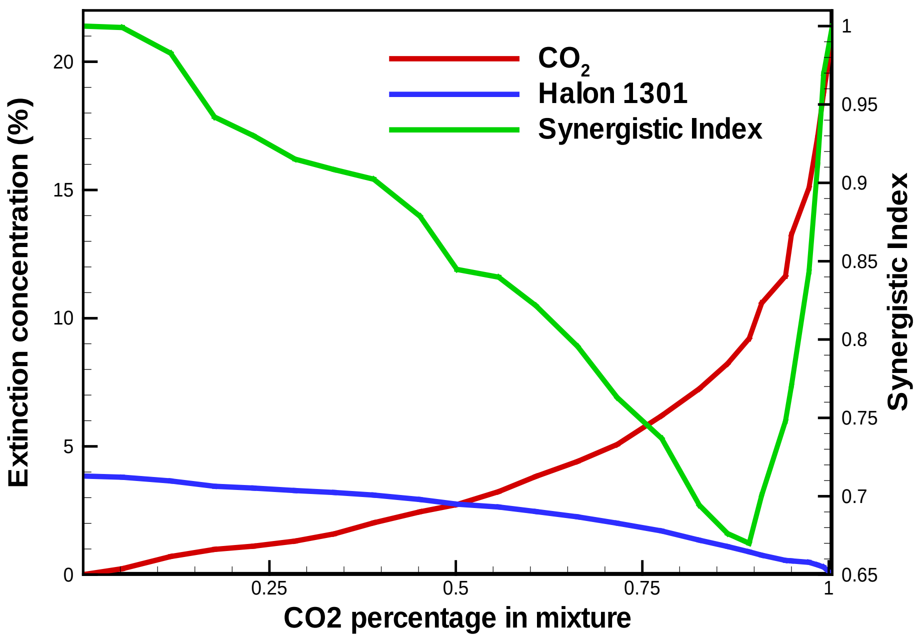
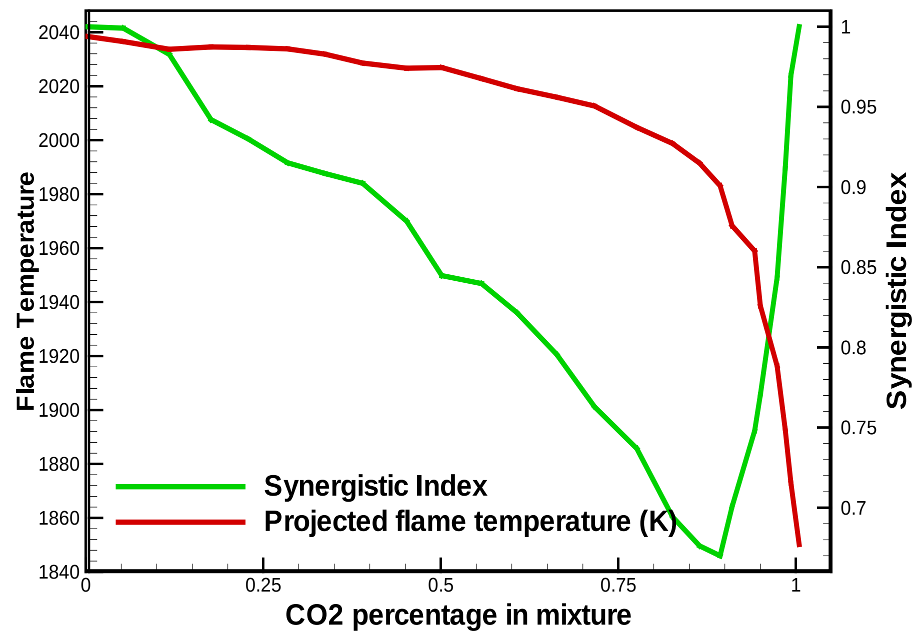
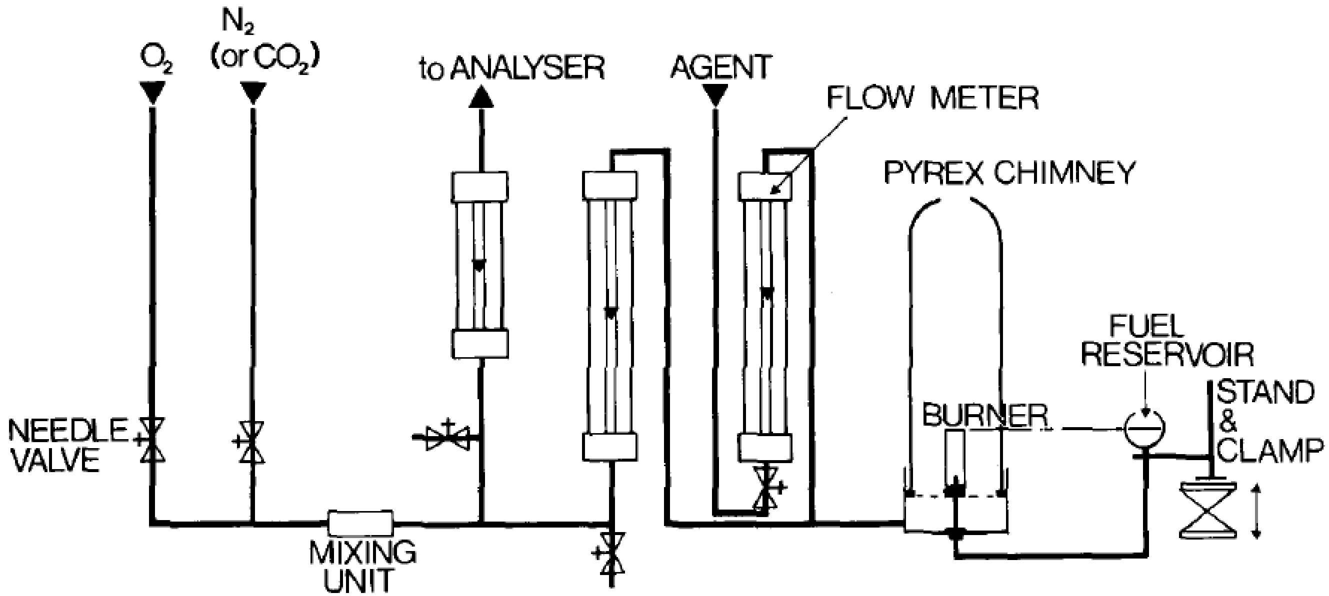




$$F = \frac{x_{1301}}{x_{1301}^{ext}} + \frac{x_{CO_2}}{x_{CO_2}^{ext}}$$

Lott, J.L., Christian, S.D., Sliepcevich, C.M., Tucker, E.E., Synergism between Chemical and physical fire-suppressant agents, Fire Technology, Vol 32, No. 3, 1996



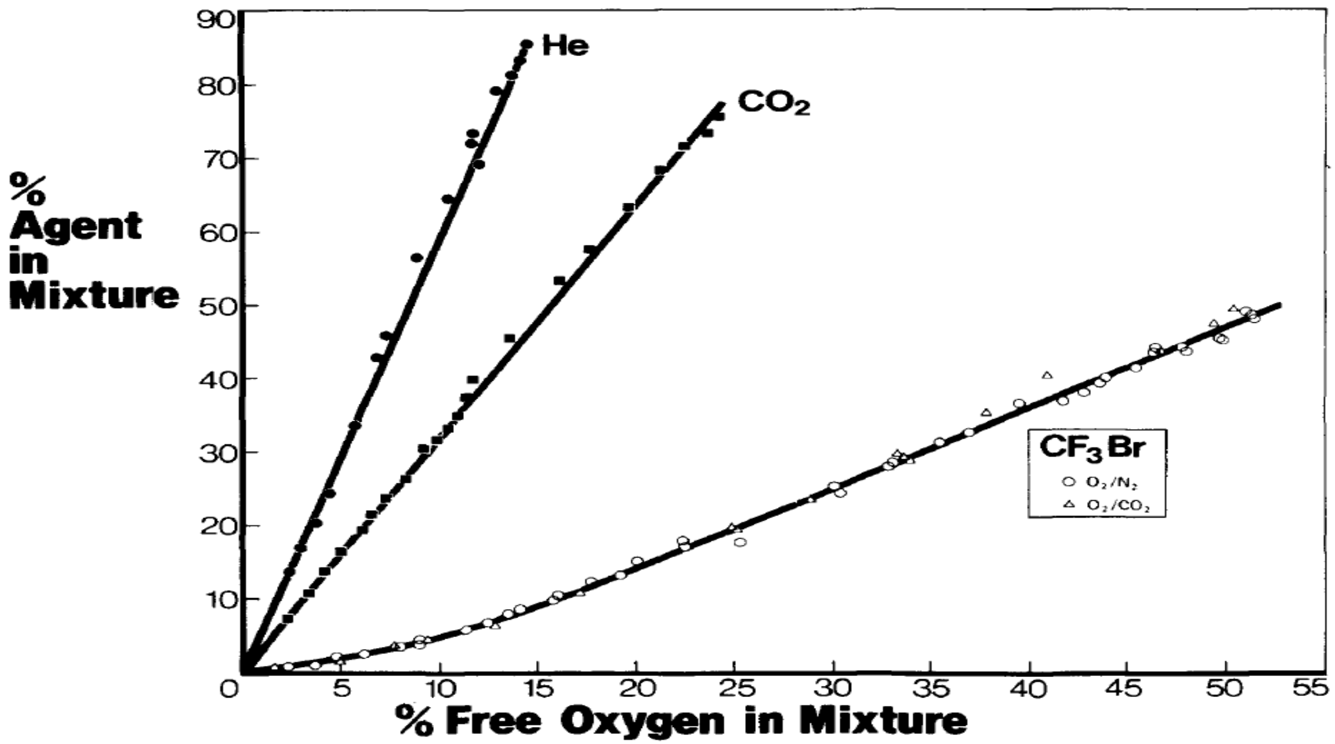
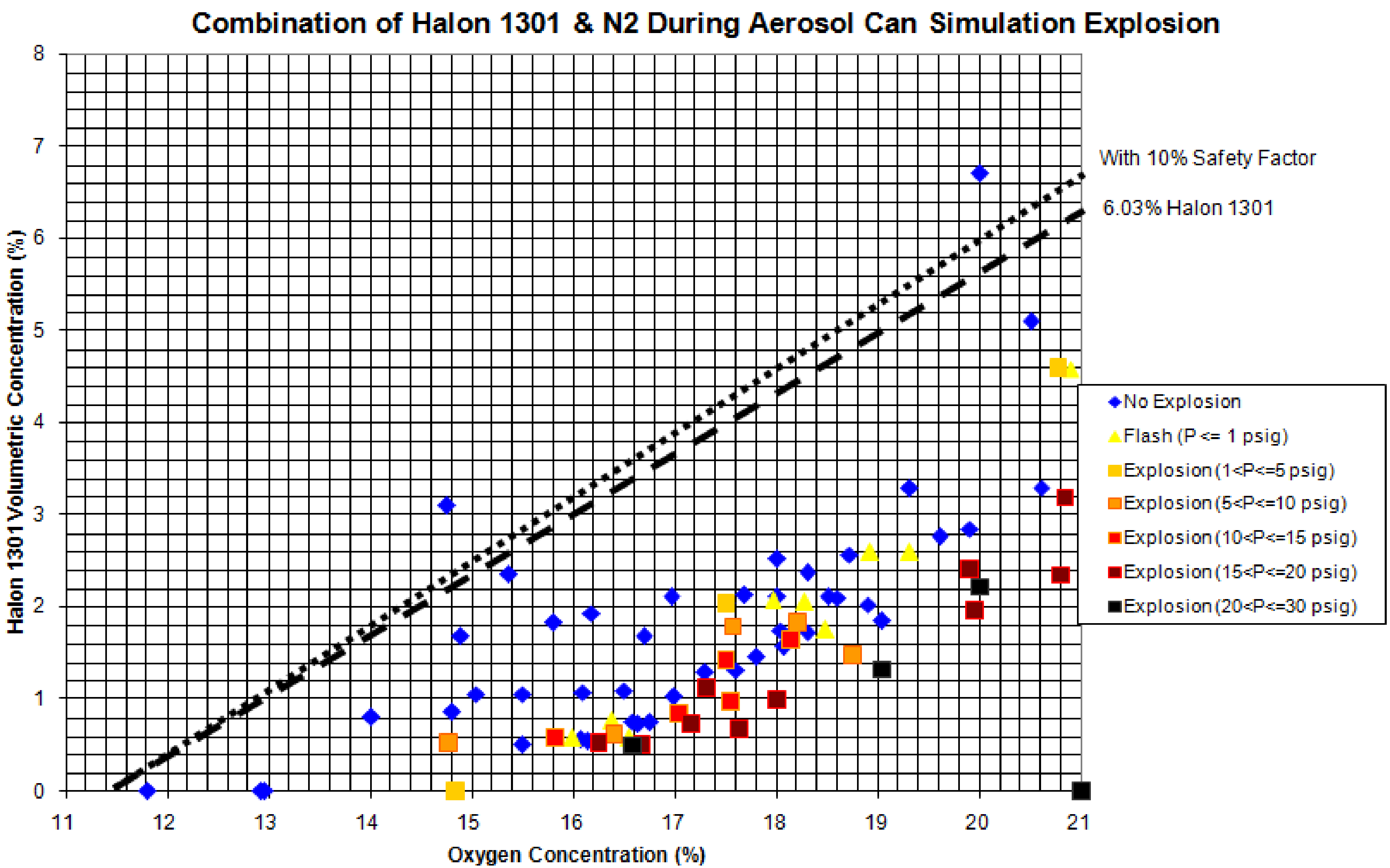


Fig. 2. Concentrations of He, CO_2, and CF_3Br required to extinguish an *n*-hexane flame at various "free oxygen concentrations" (Eq. 8).

FAA suppression experiments



Conclusions

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- Flame extinction is a thermal behavior governed by energy balance.
- Without the synergistic/catalytic effects, the inerting concentrations of a thermal agent are predictable based on the flammability of the fuel.
- Most agents work by mass, while the flame temperature is a good indicator of synergistic effects.
- The thermal view on suppression is not conflicting with the traditional chemical view. The advantage is a simple tool to manipulate binary agents.