Oxygen Partial Pressure and Oxygen Concentration Flammability: Can They Be Correlated?

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The Partial Pressure Question

• Assuming an Ideal gas mixture
  21% volume O₂ = 21 mole % O₂
  \((v_{O₂}/V) = p_{O₂}/P\)
  \(p_{O₂} = (v_{O₂}/V) \times P\)

• If the available oxidizer is the driver for combustion then should flammability for…..

  30% O₂, 10.2 psi (3.1pp) = 100% O₂, 3.1psi (3.1pp)
Test Method and Environmental Conditions

- Flammability Data Examined
  - Primarily NASA-STD-6001 Test 1 Maximum Oxygen Concentration self-extinguishment thresholds
    - 6” Self Extinguishment Criteria
    - Vary Oxygen Concentration until a threshold is identified for Self Extinguishment to occur.
    - Threshold allows performance comparisons across environments of equivalent O2 PP
  - Material ignition susceptibility
  - Burn Rates
Max O₂ Concentration Self Extinguishment Thresholds & Equivalent Normoxic O₂ Concentrations (NASA 6001 Flamm)
Max O₂ Total Pressures Self Extinguishment Thresholds & Equivalent Partial Pressures (NASA 6001 Flamm)

![Graph showing Max O₂ Total Pressures and Partial Pressures for various materials.](image)

- **PTFE**
- **Kelf-81**
- **Silicone**
- **Zytel 42**
- **Viton-A**
- **Buna-S**
- **Buna-N**
- **EPDM Rubber**
- **Polyethylene (PE)**
- **Delrin**
- **Zoteck F30**
- **Velox DR48**
- **Nylon/Phenolic**
- **Aramid TG4060**
- **Sygef**
- **Udel P1700 Polysulfone**
- **Ultem 1000**
- **Melamine/Glass**
- **Melinex 515**
- **Kydex 100**
- **Nomex 90-40**
- **Normoxic PP equivalents (CEV/ST5)**
- **ISS PP equivalents**

**Equations and Regression Coefficients:**

- \( y = 6.0351x - 4.1075 \) \( R^2 = 0.99317 \)
- \( y = 1.382x^{1.5944} \) \( R^2 = 0.99678 \)
- \( y = 6.1301x - 2.1095 \) \( R^2 = 0.99943 \)
- \( y = 1.42x^{1.3114} \) \( R^2 = 0.99978 \)
- \( y = 1.1153x^{2.0465} \) \( R^2 = 0.99999 \)
Total Pressure Dependencies

• For pressures above 41 kPa (6 psia)
  – All show a strong dependence on oxygen concentration with little relation to total pressures

• Below 41 kPa (6 psia)
  – MOCs and required oxygen partial pressures show increased dependence on total pressure.

• Power equation models fit trends precisely across
  – Pressure ranges spanning 2.8–119.3 kPa (0.4–17.3 psia)
  – Both MOC and partial pressure against total pressures.

• Required $\text{O}_2$ partial pressure necessary to sustain propagation decreases with decreased total pressures.
  – Increased flammability risk at lower total pressure conditions despite equivalent partial pressure
  – Conversely, oxygen concentration primary driver despite equivalent partial pressure
Application of Findings

- Lower O$_2$% / higher P data **cannot** be conservatively applied to higher O$_2$% / lower P environments despite equivalent partial pressures.

\[
\text{21 O}_2\% , 14.7\text{psi}(3.1\text{pp}) \quad \cancel{\rightarrow} \quad \text{30 O}_2\% , 10.2\text{ psi}(3.1\text{pp})
\]

- Higher O$_2$% / lower P data **can** be conservatively applied to evaluate the risk of lower O$_2$% higher P equivalent PP environments.

\[
\text{30 O}_2\% , 10.2\text{psi}(3.1\text{pp}) \quad \check{\rightarrow} \quad \text{21 O}_2\% , 14.7\text{psi}(3.1\text{pp})
\]
Other Supporting Research

• Flame spread rate testing (Olson and Miller)
  – Performed along normoxic curve (18-100 O₂%)
  – Flame spread rate increased with higher O₂% despite O₂ pp remaining constant

• Burn Rates (Yang, Hamins, and Donneley)
  – Polymethyl methacrylate (PMMA) spheres
  – Burn rates increased significantly as O₂% was increased (19.9-30 O₂%)
  – little effect was observed with increased pressures from 50.0–150 kPa (7.25–21.75 psia).
Increased Pressure Dependencies

• Certain materials exhibited higher dependencies on total pressure
  – Kel-F (CF$_2$CCIF)$_n$, PTFE (C$_2$F$_4$)$_n$, Zotek F30 (C$_2$H$_2$F$_2$)$_n$,
    • highly halogenated
  – Armalon TG4060
    • fluorocarbon fiberglass composite, saturated chains of highly electronegative
      halogenated molecules (F, Cl)
    – Nomex
    – aramid structure with dense electron clouds

• All highly stable with few susceptible reaction sites.
  – Oxygen Molecular Collision Rate Competition for Reaction Sites?
Ignition Sequence

- Available Reaction Sites Ignition Sequence Pyrolysis
  1. Flammable gas mixing
  2. Ignition induction

- Proposed additional mechanism step in ignition sequence

- Limited Reaction Sites Ignition Sequence
  1. Oxygen molecular collision rate competition for reaction sites
  2. Pyrolysis
  3. Flammable gas mixing
  4. Ignition Induction

- Theory would be successful in describing observed experimental trends
Future Work

• Additional testing in low pressure ranges
• Acquisition of burn rate data at the various equivalent partial pressure conditions.
Conclusions

• Partial pressure of oxygen equivalency does not represent flammability equivalency
• Oxygen Concentration % is the primary driver for flammability despite equivalent partial pressure
• Higher O₂% /lower P data can be conservatively applied to evaluate the risk of lower O₂% higher P equivalent PP environments

21 O₂%, 14.7 psi (3.1 pp)  →  30 O₂%, 10.2 psi (3.1 pp)

30 O₂%, 10.2 psi (3.1 pp)  →  21 O₂%, 14.7 psi (3.1 pp)
Back-up Slides
Pressure effects on Self Extinguishment Thresholds & Normoxic & ISS environment conditions for comparison

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MOC = Maximum oxygen concentration which consistently results in material self-extinguishment
MOP = Maximum oxygen partial pressure when extinguishment occurs (based on MOC with the exception of 99.8% testing)
Pressure Effects on NASA STD-6001 Test 1 Maximum O$_2$ Concentration Flammability Thresholds

![Graph showing maximum oxygen concentration (MOC) vs. total pressure for various materials.](image-url)