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

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The Partial Pressure Question

- Assuming an Ideal gas mixture

$$21\% \text{ volume } O_2 = 21 \text{ mole } \% \; O_2$$

$$(v_{O2}/V) = p_{O2}/P$$

$$p_{O2} = (v_{O2}/V) * P$$

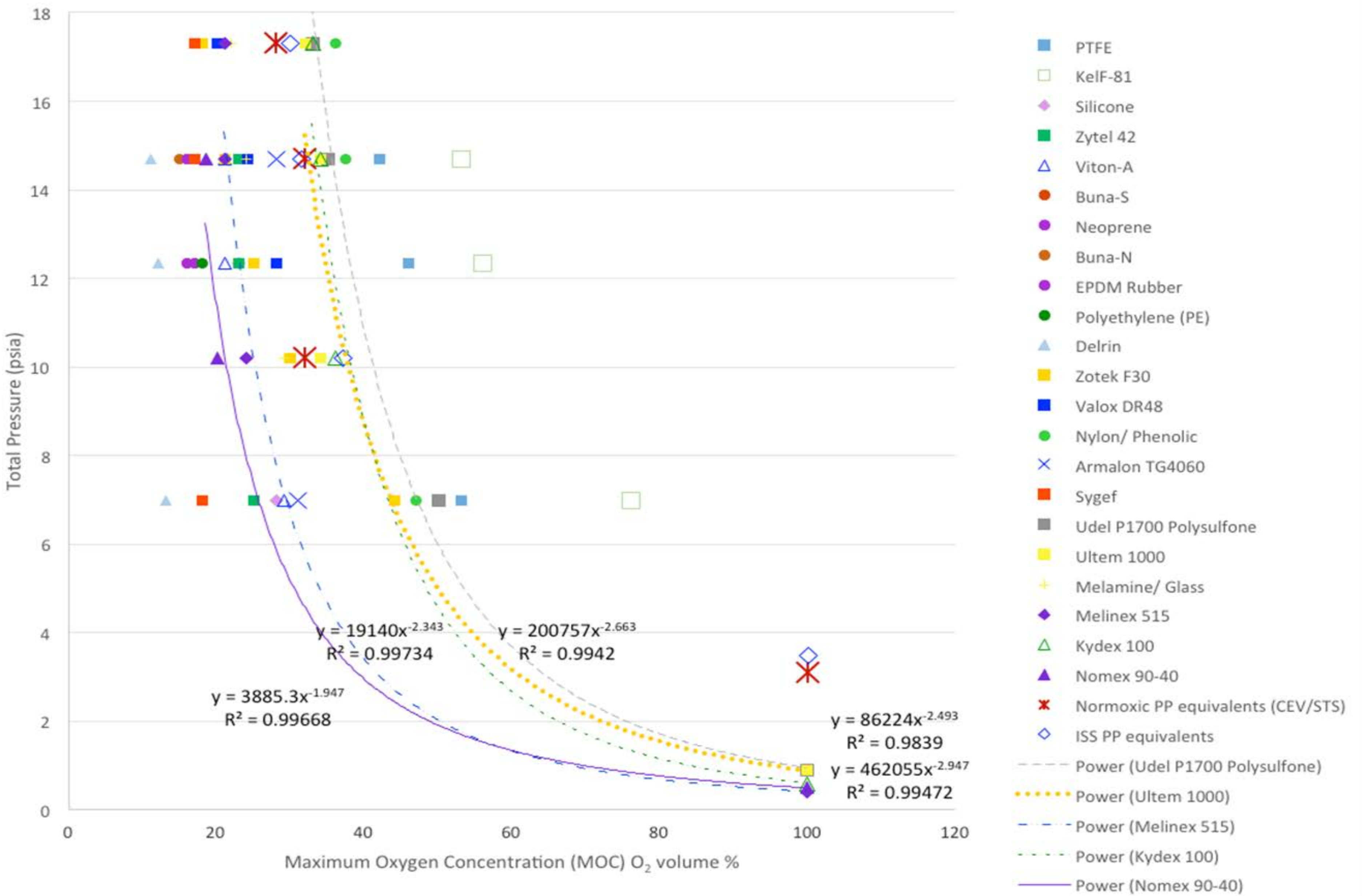
- If the available oxidizer is the driver for combustion then should flammability for.….

30% O_2,10.2 psi (3.1pp) = 100% O_2,3.1psi (3.1pp)

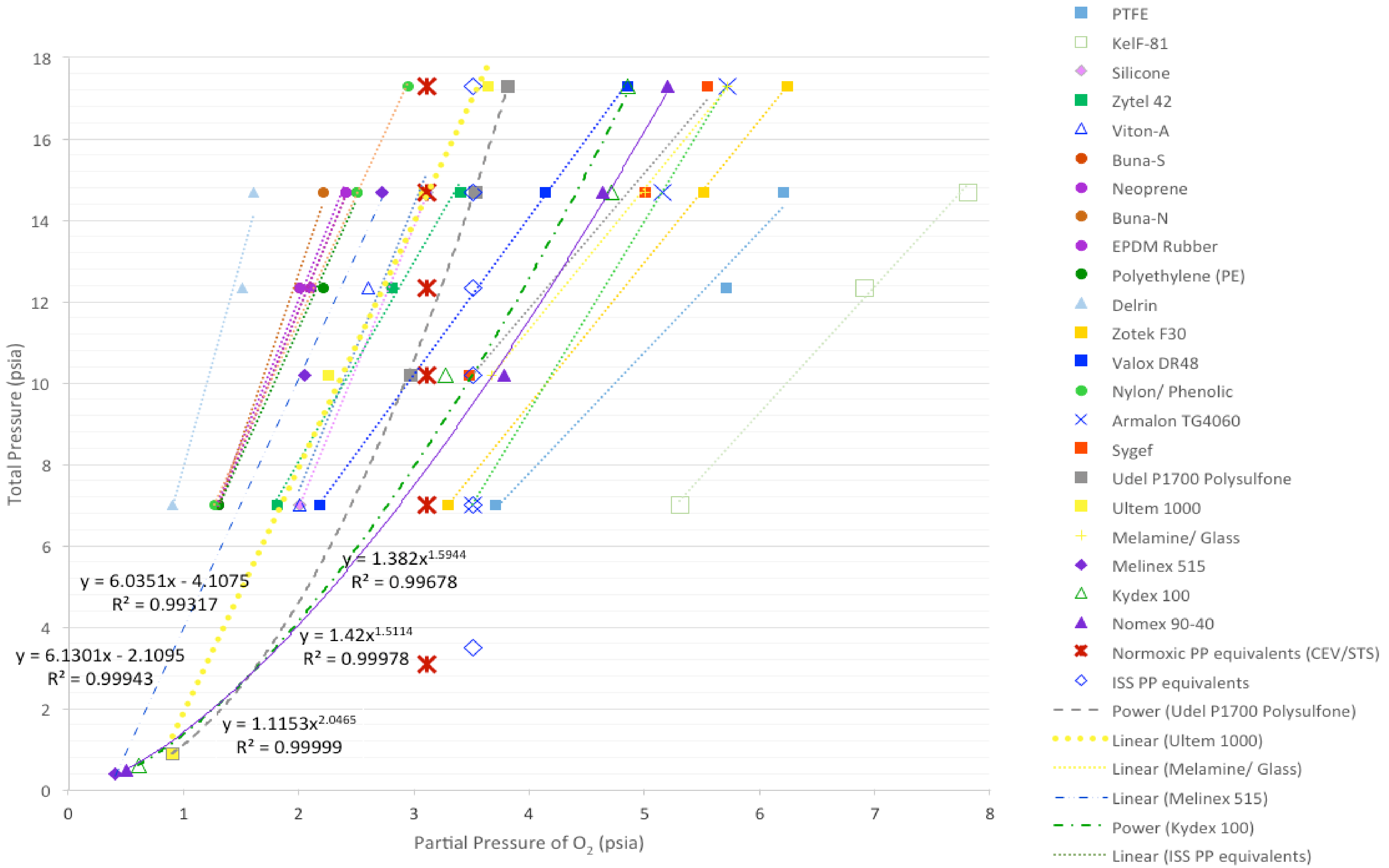
Test Method and Environmental Conditions

- 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 O_2 Concentration Self Extinguishment Thresholds & Equivalent Normoxic O_2 Concentrations (NASA 6001 Flamm)



Max O_2 Total Pressures Self Extinguishment Thresholds & Equivalent Partial Pressures (NASA 6001 Flamm)



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 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 <u>cannot</u> be conservatively applied to higher O_2% /lower P environments despite equivalent partial pressures.

21 O_2%,14.7psi(3.1pp) → 30 O_2%,10.2 psi(3.1pp)

- Higher O_2% /lower P data <u>can</u> be conservatively applied to evaluate the risk of lower O_2% higher P equivalent PP environments

30 O_2%,10.2 psi(3.1pp) → 21 O_2%,14.7psi(3.1pp)

Other Supporting Research

- Flame spread rate testing (Olson and Miller)
  - Performed along normoxic curve (18-100 O_2%)
  - Flame spread rate increased with higher O_2% despite O_2 pp remaining constant
- Burn Rates (Yang, Hamins, and Donneley)
  - Polymethyl methacrylate (PMMA) spheres
  - Burn rates increased significantly as O_2% was increased (19.9-30 O_2%)
  - 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 $(CF_2CClF)n$, PTFE $(C_2F_4)n$, Zotek F30 $(C_2H_2F_2)n$,
    - 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 O_2% /lower P data <u>can</u> be conservatively applied to evaluate the risk of lower O_2% higher P equivalent PP environments

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Back-up Slides

Pressure effects on Self Extinguishment Thresholds & Normoxic & ISS environment conditions for comparison

Material	psia (total pressure)													
	Determined at 99.8 % volume O_2													
	0.4	0.5	0.6	0.9	7		10.2		12.35		14.7		17.3	
	MOP (psia)	MOP (psia)	MOP (psia)	MOP (psia)	MOC (vol%)	MOP (psia)	MOC (vol%)	MOP (psia)	MOC (vol%)	MOP (psia)	MOC (vol%)	MOP (psia)	MOC (vol%)	MOP (psia)
PTFE					53	3.7			46	5.7	42	6.2		
KelF-81					76	5.3			56	6.9	53	7.8		
Silicone					28	2.0			23	2.8	21	3.1		
Zytel 42					25	1.8			23	2.8	23	3.4		
Viton-A					29	2.0			21	2.6	21	3.1		
Buna-S					18	1.3			17	2.1	16	2.4		
Neoprene					18	1.3			17	2.1	16	2.4		
Buna-N					18	1.3			16	2.0	15	2.2		
EPDM Rubber					18	1.3			16	2.0	16	2.4		
Polyethylene (PE)					18	1.3			18	2.2	17	2.5		
Delrin					13	0.9			12	1.5	11	1.6		
Zotek F30					47	3.3					37.5	5.5	36	6.2
Valox DR48					31	2.2					28.1	4.1	28	4.8
Nylon/ Phenolic					18	1.3					17	2.5	17	2.9
Armalon TG4060					50	3.5					35	5.1	33	5.7
Sygef							34	3.5			34	5.0	32	5.5
Udel P1700 Polysulfone				0.9			29	3.0			24	3.5	22	3.8
Ultem 1000				0.9			24	2.4			21	3.1	21	3.6
Melamine/ Glass							36	3.7			34	5.0	33	5.7
Melinex 515	0.4						20	2.0			18.5	2.7		
Kydex 100			0.6				32	3.3			32	4.7	28	4.8
Nomex 90-40		0.5					37	3.8			31.5	4.6	30	5.2
Normoxic environment partial pressure equivalents (CEV/STS)					44	3.1	30	3.1	25	3.1	21	3.1	18	3.1
ISS environment partial pressure equivalents					50	3.5	34	3.5	28	3.5	24.1	3.5	20	3.5

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