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A PILOT STUDY ON HYPOXIC AIR PERFORMANCE AT THE INTERFACE OF FIRE PREVENTION AND FIRE SUPPRESSION

FireSEAT 2011 – The Science of Suppression

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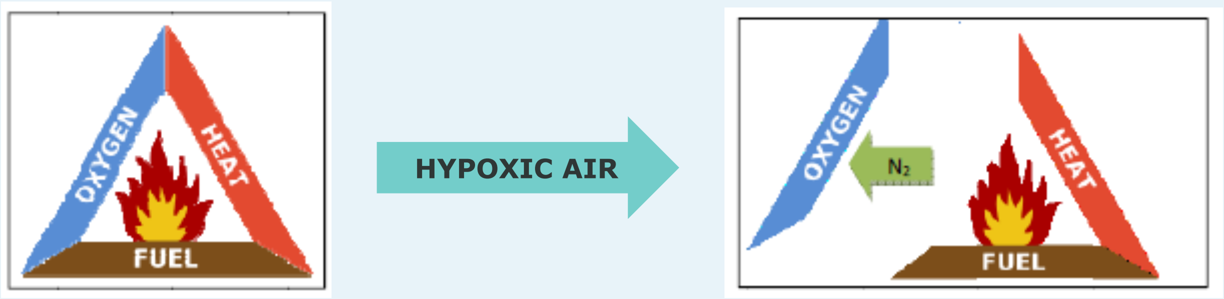
Hypoxic Air Technology (HAT): what is it?

- **Hypoxic Air Technology:**
  - Fire prevention technology based on a continuous reduction of O_2 in the protected volumes.
  - When even fire suppression is not acceptable.
  - Typically 14-15 vol% O_2 , 85-84 vol% N_2 for fire prevention.
  - Lower O_2 concentrations for fire suppression (consistent with gas extinguishing systems).

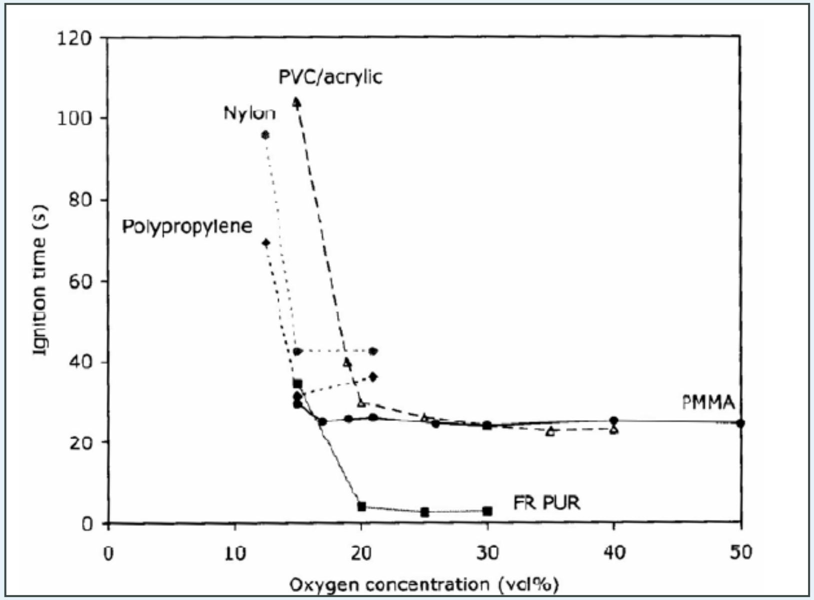


Effects of low O_2 concentration on ignition and combustion

- **Minimum Oxygen Concentration (MOC) : below MOC no combustion**
  - depends on the diluent used to reduce O_2
  - if diluent is N_2 : $MOC = LFL \cdot \frac{1}{4.77} \cdot \left(\frac{100}{C_{st}} - 1 \right)$
    - where LFL is the Lower Flammable Limit, C_{st} is the stoichiometric oxygen/fuel concentration
  - similar relationship also for dust clouds
  - MOC for fire prevention is not the same as for fire suppression

Effects of low O_2 concentration on ignition and combustion

- **Ignition time: increases when lowering O_2 concentration**
  - Mc. Alevy et. al.: $t_{ign} \propto m_{O_2}^{-2/3}$
  - Kumar and Hermance: $t_{ign} \propto m_{O_2}^{-n}$
  - Mikkola, Hirsch, Hsieh:
    - PVC: +300% ignition time in O_2= 15 vol%
    - PMMA: + 24% ignition time in O_2= 15 vol%
    - Silicone elastomers: drastic increase
    - FR PUR foam: drastic increase
    - But it is not investigated what happens after ignition



Effects of low O_2 concentration on ignition and combustion

- **Autoignition time (AIT): increases when lowering O_2 concentration**
  - Kashiwagi: 15 vol% limiting O_2 value for successful autoignition
  - Experiments on AIT for gases: $AIT = \dfrac{e^{E/RT}}{[O_2]^n}$
  - Alvares: $AIT \propto P_{O_2}^{-0.25}$

- **Minimum Ignition Energy (MIE): rises when decreasing O_2 concentration**
  - Experiment on gases: $MIE \propto OI^{-n}$
    - where Oxygen Index $OI = O_2/(O_{2+}\ N_2)$; n = 4 (Chinn) or n = 2.5 (Von Elbe)

Effects of low O_2 concentration on ignition and combustion

- **Flame spread velocity (V): decreases at low O_2 concentrations**
  - Studies reported by Babrauskas: $V \propto m_{O_2}{}^{n}$
    - where n = 2 or n = 1

- **Mass loss rate (MLR): decreases at low O_2 concentrations**
  - Santo and Tewarson: MLR - 30% in O_2 = 18 vol% (PMMA)
  - Babrauskas reports: MLR'' = a·m_{oxygen} – b
    - where MLR'' is the MLR per unit of surface area, *a* and *b* are constant

- **Heat release rate (HRR): decreases drastically if O_2 concentration is low**
  - Mulholland: The heat peak decreases drastically if O_2 is lowered, and this effect is greater when approaching the lowest O_2 concentration at which combustion can be sustained.

Effects of low O_2 concentration on ignition and combustion - discussion

- Hypoxic air, by lowering O_2 concentration in the air, has several benefits regarding to the ignition and combustion processes:
  - longer ignition time
  - higher MIE
  - lower flame spread velocity
  - reduced MLR

- Oxygen concentration <= 15vol% can prevent ignition for most solid materials (hypoxic air for fire prevention).
- Oxygen concentration must be consistent with the values for gas suppression systems if hypoxic air is used in suppression mode (O_2= 12–13 vol%).

Test method to assess hypoxic air performance – aim

1. Investigate the ignition limiting properties of hypoxic air for fire prevention for different material configurations.

2. Investigate fire spread at different O_2 concentrations (vertical material configuration - worst case).

Test method to assess hypoxic air performance – test room

- $V = 10.35\ m^3$
- $H = 2.3\ m$
- Airtight room with adjoining air lock
- Door and observation windows.
- Smoke extractor fan

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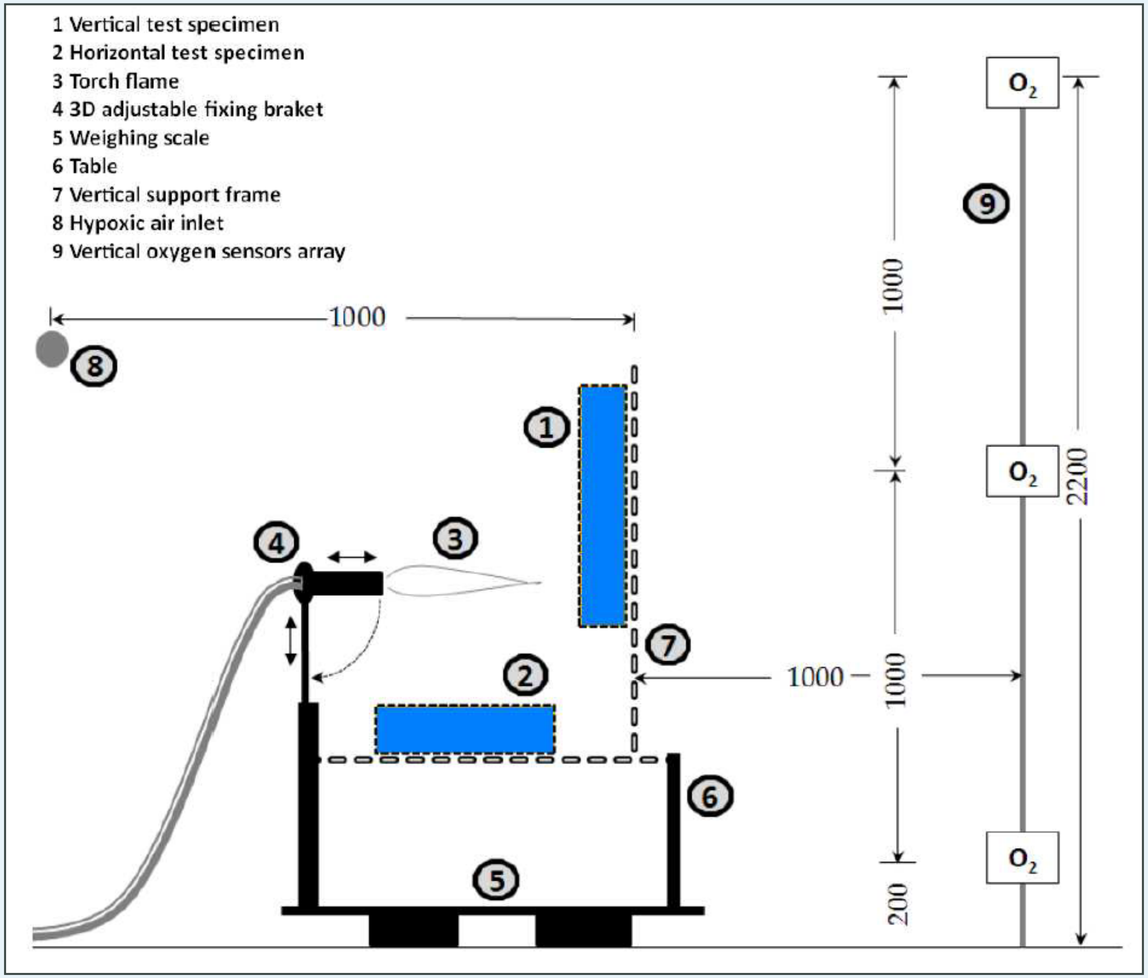
Test method to assess hypoxic air performance – equipment

- Nitrogen generator.
- O_2 sensors.
- Oxyacetylene premixed pilot flame.
- Calibrated scale.
- Support frame.
- Common specimens.



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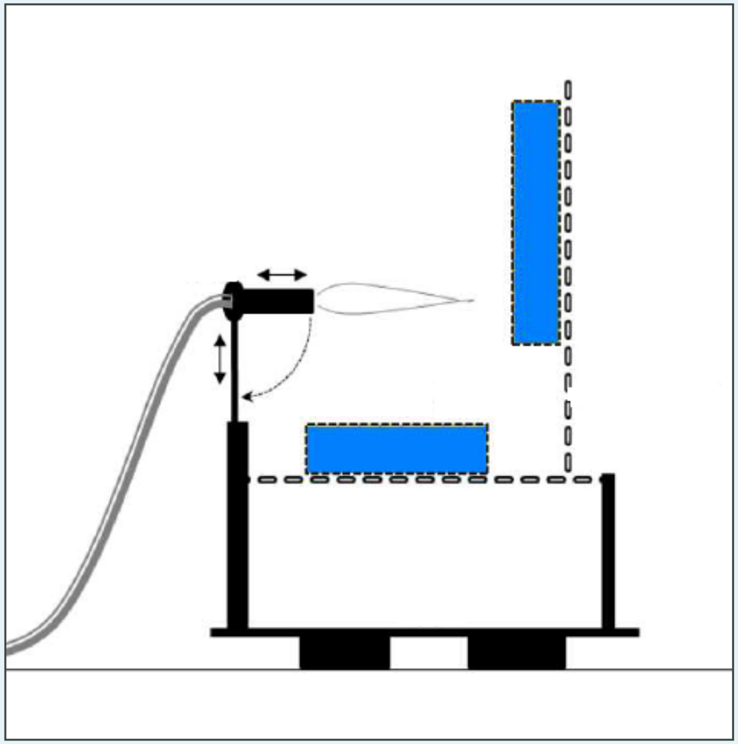
Ignition test - procedure

1. Horizontal/vertical arrangement of the test specimen, flame direction.
2. Reduce O_2 concentration in the test room (O_2 constant throughout the test)
3. Regulate pilot flame.
4. The pilot flame hit the test specimen for 180 s (FET, Flame Exposure Time).
5. Remove the pilot flame and observe the test specimen response for at least 60 s (PET, Post Exposure Time).

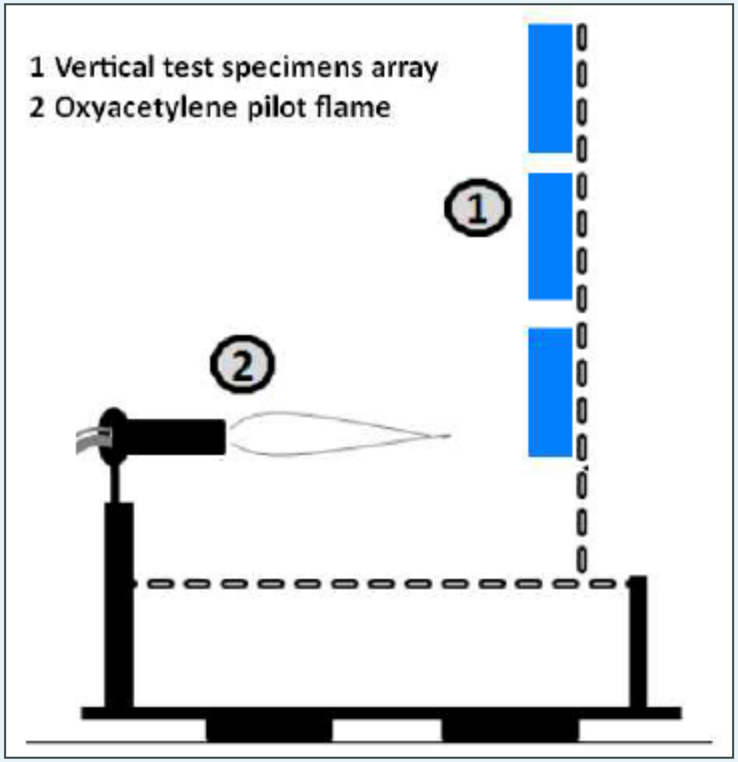


- Data on test specimen mass, O_2 concentration are continuously recorded during FET and PET.
- Consistent with BSI PAS 95, VdS 3527

Flame spread test - procedure

1. Vertical array of test specimens.
2. Reduce O_2 concentration in the test room.
3. Regulate pilot flame.
4. The pilot flame hit the bottom test specimen for 180 s.
5. Observe if flames spread to the other two specimens.

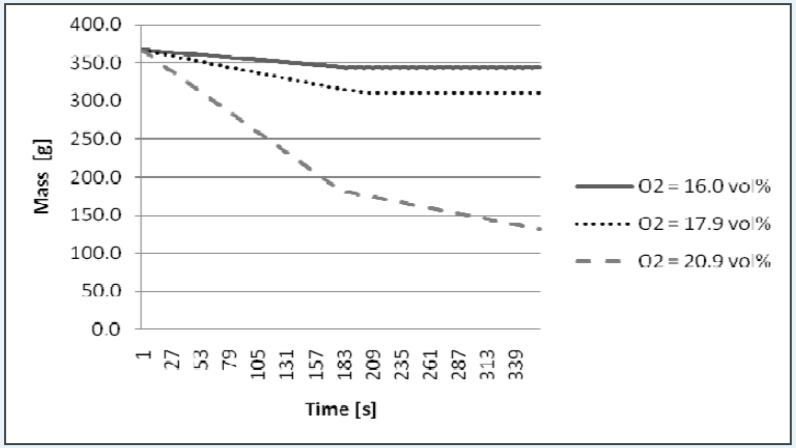
- Data on test specimens mass, O_2 concentration continuously recorded.



Ignition test – results

- **Polypropylene (PP) : horizontal configuration test.**
  - Test specimen: PP box (37x25x12 cm)
  - Ignition limiting O_2 threshold: 16.0 vol% (VdS 3527)

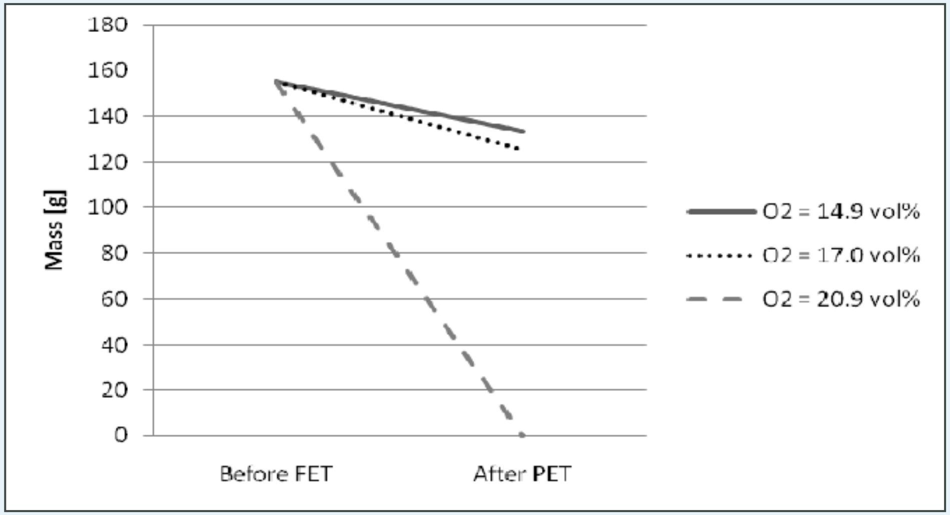
	Ignition during FET	*Self-sustained burning/flame spread during PET*
O_2 = 16.0 vol%	NO	NO
O_2 = 17.9 vol%	YES	Small flames, self-extinguishing after 20 s
O_2 = 20.9 vol%	YES	YES



Ignition test – results

- **Polypropylene (PP) : vertical configuration test.**
  - Test specimen: PP lid for box

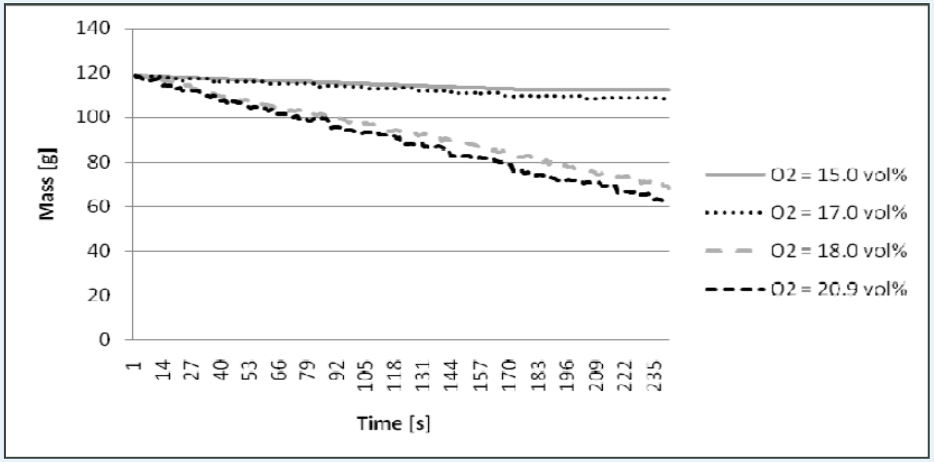
	Ignition during FET	Self-sustained burning/flame spread during PET
$O_2 = 14.9$ vol%	NO	NO
$O_2 = 17.0$ vol%	YES	NO
$O_2 = 20.9$ vol%	YES	YES



Ignition test – results

- **Paper: horizontal configuration test.**
  - Test specimen: rolled newspaper
  - Ignition limiting O_2 threshold: 14.1 vol%

	Ignition during FET	*Self-sustained burning/flame spread during PET*
O_2 = 14.9 vol%	NO	NO
O_2 = 17.0 vol%	YES	Pyrolizing fire
O_2 = 18.0 vol%	YES	YES
O_2 = 20.9 vol%	YES	YES



Ignition test – results

- **ISO wood crib: horizontal configuration test.**
  - Test specimen: ISO wood crib, mini crib type, 5 layers each crib, 2 members each layer, total volume 78 cm^3.
  - Test specimen moistened with pure alcohol.
  - Ignition limiting O_2 threshold: 17.0 vol% (untreated wood, VdS 3527)

	Ignition during FET	*Self-sustained burning/flame spread during PET*
$O_2 = 14.9$ vol%	YES	Small flames, self-extinguishing after 10 seconds.
$O_2 = 16.0$ vol%	YES	Small flames, self-extinguishing after 120 seconds.
$O_2 = 17.0$ vol%	YES	Flames, self-extinguishing after 180 seconds.
$O_2 = 18.0$ vol%	YES	YES
$O_2 = 19.0$ vol%	YES	YES
$O_2 = 20.0$ vol%	YES	YES
$O_2 = 20.9$ vol%	YES	YES

Ignition test – results

	Initial mass	Mass lost during FET	Mass lost during PET	Mass loss during FET+PET	Final mass
O_2 = 14.9 vol%	16.9 g	13.61 %	2.37 %	15.98 %	14.2 g
O_2 = 16.0 vol%	16.9 g	14.20 %	27.81 %	42.01 %	9.8 g
O_2 = 17.0 vol%	16.9 g	16.57 %	55.03 %	71.60 %	4.8 g
O_2 = 18.0 vol%	16.9 g	14.20 %	77.51 %	91.71 %	1.4 g
O_2 = 19.0 vol%	16.7 g	--------	--------	96.41 %	0.6 g
O_2 = 20.0 vol%	16.8 g	--------	--------	97.62 %	0.4 g
O_2 = 20.9 vol%	16.6 g	--------	--------	100 %	0.0 g

Before test **O_2 =15.0 vol%** **O_2 = 16.0 vol%** **O_2 = 17.0 vol%**

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Ignition test – an example

O_2 = 14.9 vol%

O_2 = 20.9 vol%

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Fire spread test - results

- Test specimen: two wicker boards and a newspaper arranged in a vertical array.

	Flame spread	*Mass loss*	*Visual observations*
O_2 = 15.9 vol%	NO	3.89 %	Only the bottom wicker board (the one directly hit by the pilot flame) ignited.
O_2 = 20.9 vol%	YES	82.39 %	The fire spread almost immediately to all the three specimens.

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Fire spread test - results

O_2= 15.9 vol%

O_2= 20.9 vol%

10s 60s 300s

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Test series - discussion

- Most test specimens did not ignite during the test performed at the lowest O_2 concentration (PP, paper).
  - Exception: wood crib (note: extremely severe heat source, alcohol).

- Difficult to ignite between 16.0 vol% and 17.0 vol% of O_2 concentration, flame and burning self-extinguished during PET, reduction in mass loss.

- No flame spread in the test performed at O_2 = 15.9 vol%.

- For the majority of the materials tested there is a sort of a response threshold in terms of burning between 17.0 vol% and 18.0 vol% of O_2 concentration.

Conclusions

- $14.5 \leq O_2 \leq 15.0$ vol% : hypoxic air limits ignition, prevents flame spread for all investigated materials.

- $16.0 \leq O_2 \leq 17.0$ vol%: hypoxic air does not fully prevent ignition but does lessen fire damages.

- Accurate assessment of materials, configuration and hazards to determine the correct O_2 concentration.

- More research to exploit and optimize further the potential of Hypoxic Air Technology.

Acknowledgments

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Thank you for your attention!