Flame Ignition and Particulate Formation in Oxy-Coal Combustion Systems

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Presented at
ACERC Meeting,
Brigham Young University, Provo, Utah
Feb 25th and 26th, 2010

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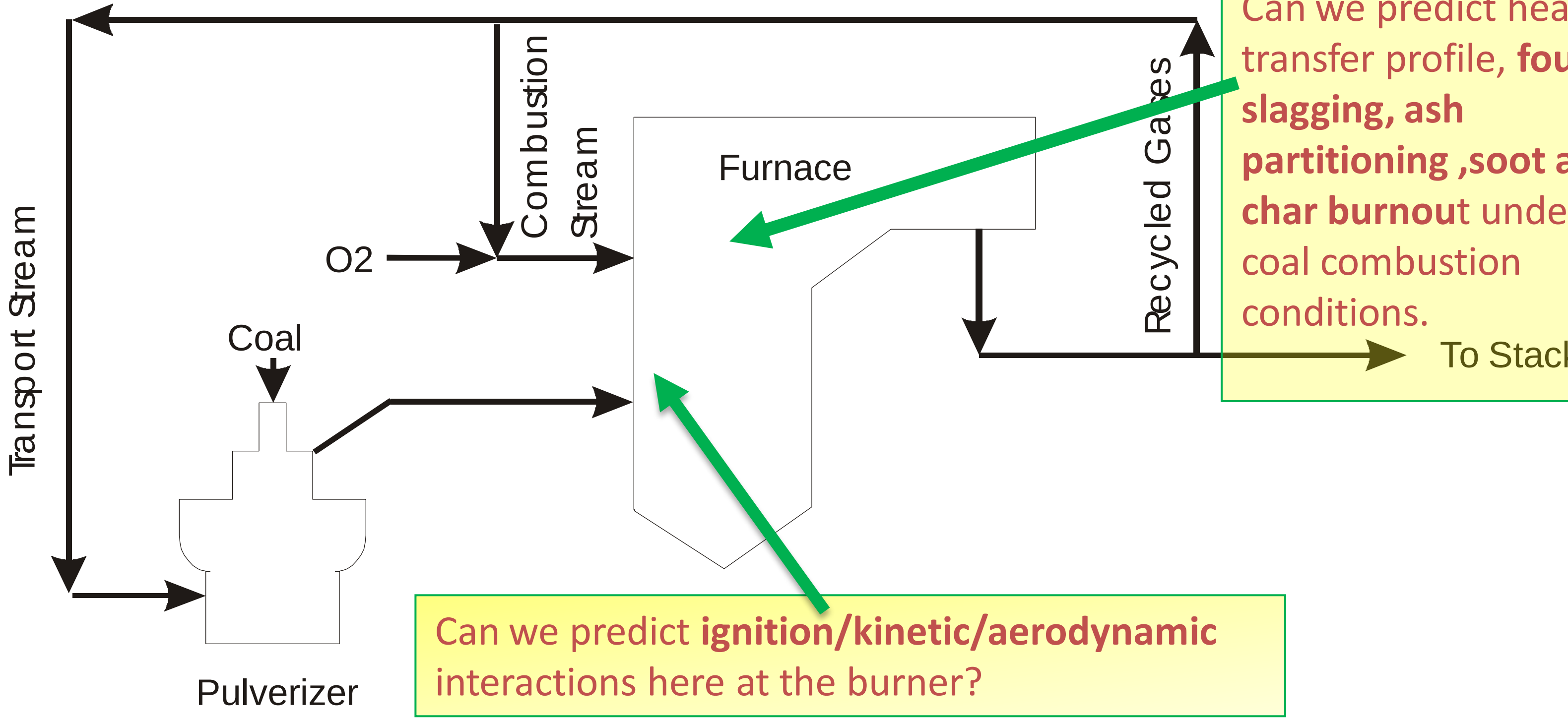
Oxy-Coal Combustion (short term research needs):

Schematic of oxygen fired PC furnace with CO_2 recycle (adapted *Sarofim et al, 2004*)

Where should the recycled gases be taken from?
After: ash removal? H_2O removal? SO_2 removal?



Can we predict heat transfer profile, **fouling, slagging, ash partitioning ,soot and char burnout** under oxy-coal combustion conditions.

Can we predict **ignition/kinetic/aerodynamic** interactions here at the burner?

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Oxy-coal research at the University of Utah using a 100kW (nominal) down-fired oxy-fuel combustor (OFC)

1. Flame ignition studies
   a) Focus on mechanisms of interaction between turbulent mixing in co-axial flows and coal ignition mechanisms
   b) Effect of P_{O2} , and substitution of CO_2 by N_2 in *primary* fuel stream.
   c) Effect of P_{O2} and preheat in *secondary* oxidant stream

2. Ultra-fine particles, soot, LOI and ash
   a) Ultra-fine particles, soot and carbon
      - How does oxy-coal firing affect soot and ultra-fine particle formation?
      - Relationship between ultra-fine PSD, soot and LOI
   b) Ash partitioning studies
      - How does oxy-coal firing affect ash aerosol size segregated composition and morphology

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1. Flame ignition studies

- Determine, in a systematic manner, how burner operating parameters and oxygen partial pressure influence flame stability and coal ignition.
- Explore effects of variations in the partial pressure of O_2 and CO_2 on coal jet ignition and flame stability(specific objective of this work).
- Systematically investigate near-burner aerodynamics and ignition zone for Type 0 axial diffusion flames (no swirl)
- Develop technique to quantify coal flame length or stand-off distance from photo-images to allow quantitative comparison with simulations, together with uncertainty quantification.

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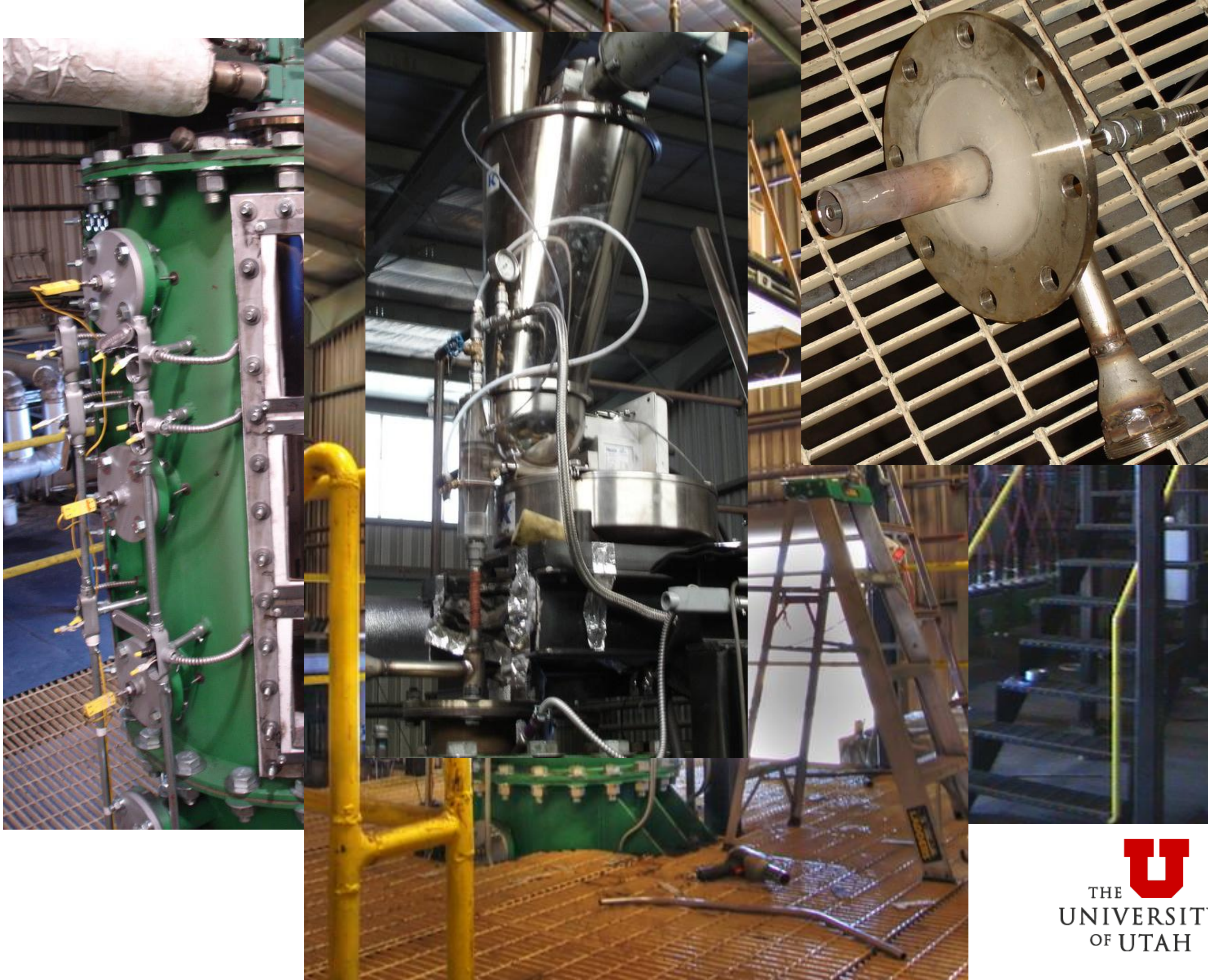

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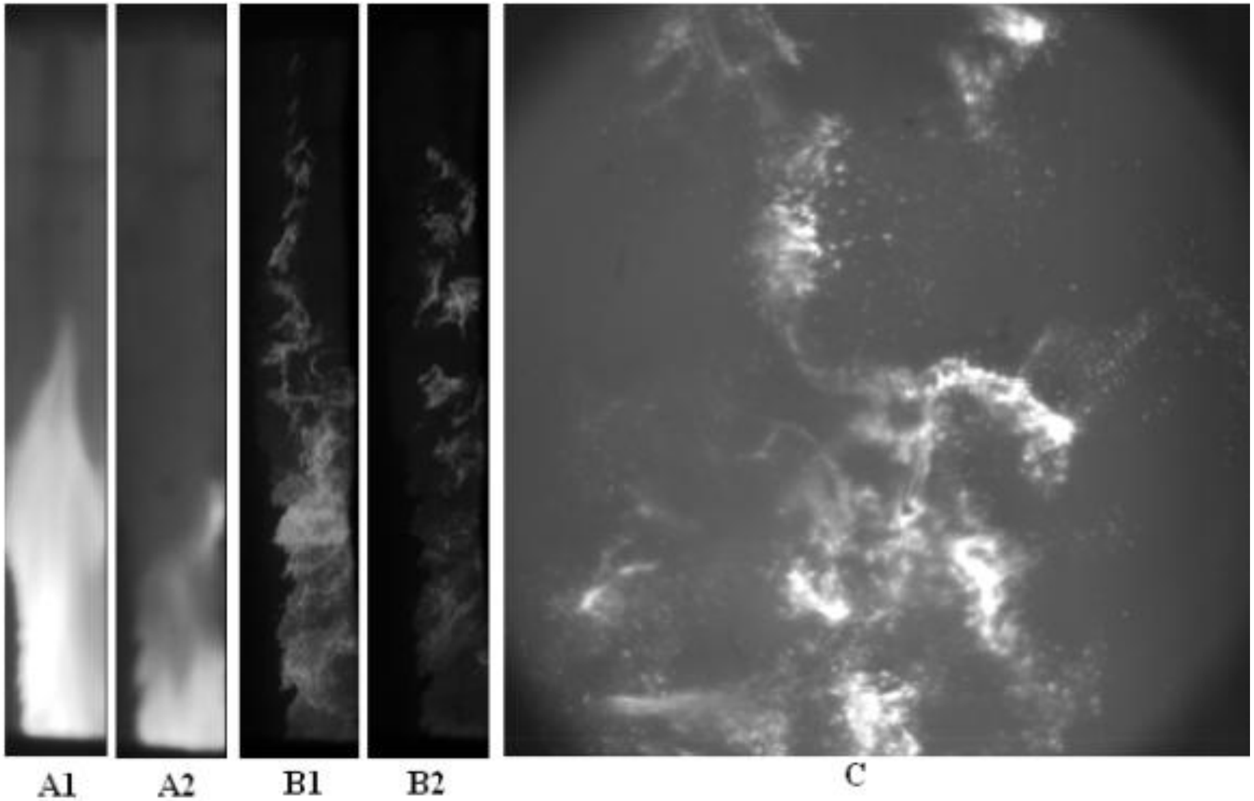
Definition and quantification of flame stand-off distance

Depends on camera shutter speed (and, in practice, on the averaging process of the human eye)



Flame images *of different fl*ames collected with different cameras/settings showing the effect of improved temporal resolution (left to right). Frames A1 and A2, collected with an EPIX CMOS camera SV5C10, show an exposure time of 8.3ms and a collection rate of 30 frames per second (fps). Frames B1 and B2, collected with a Nikon DSLR camera D5000, show an exposure time of 0.25 ms and a collection rate of 4 fps, while Frame C, collected with a Photron high speed camera, shows an exposure time of 5μs and a collection rate of at 5000 fps.

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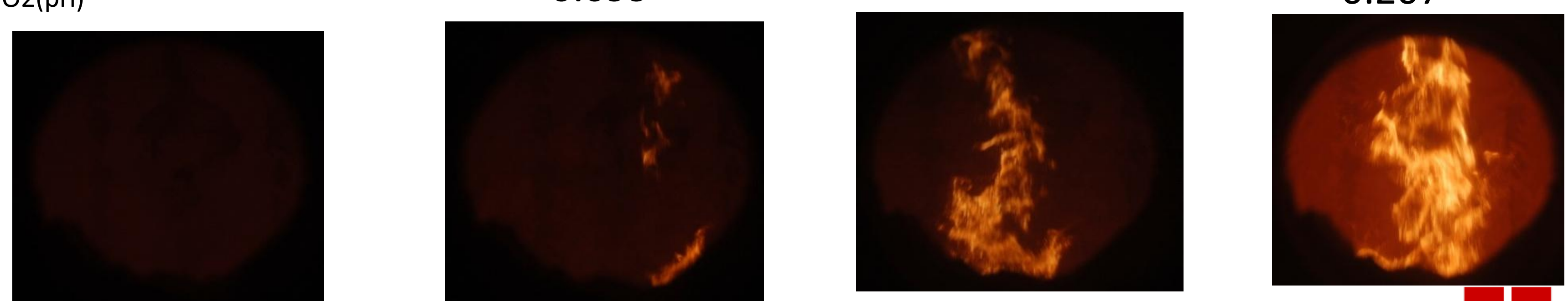
$P_{O2(pri)} = 0.0$ 0.099 0.144 0.207



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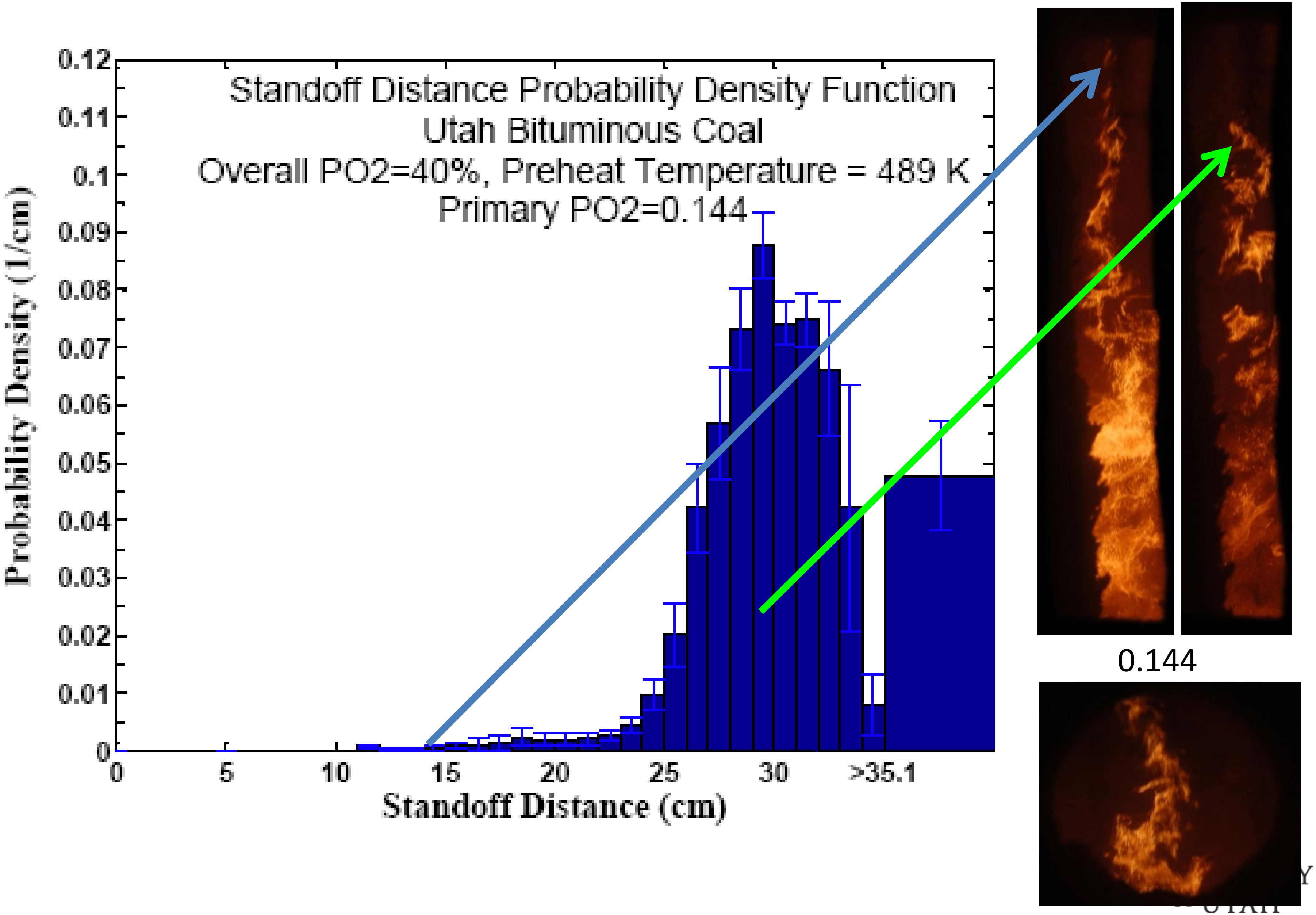
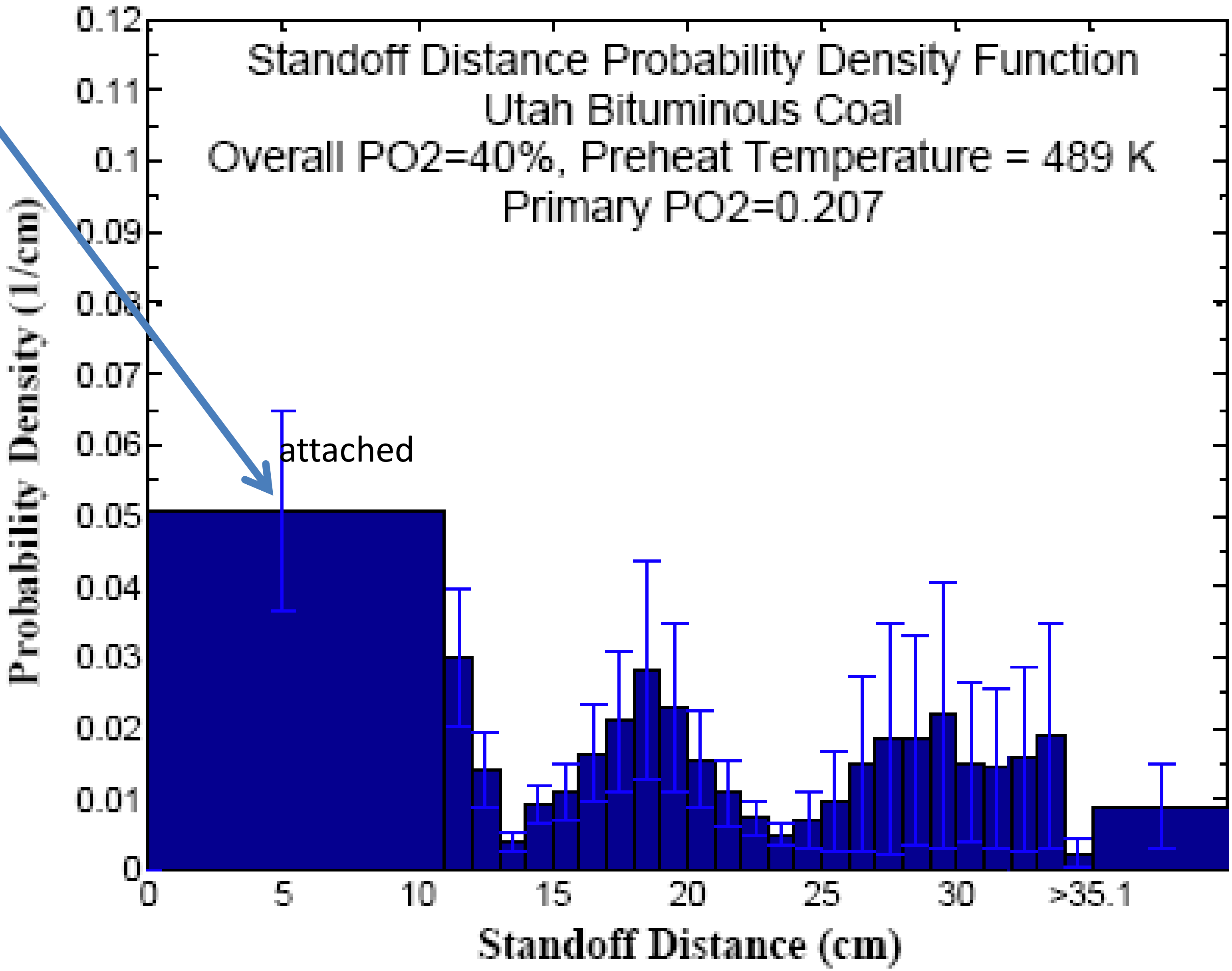
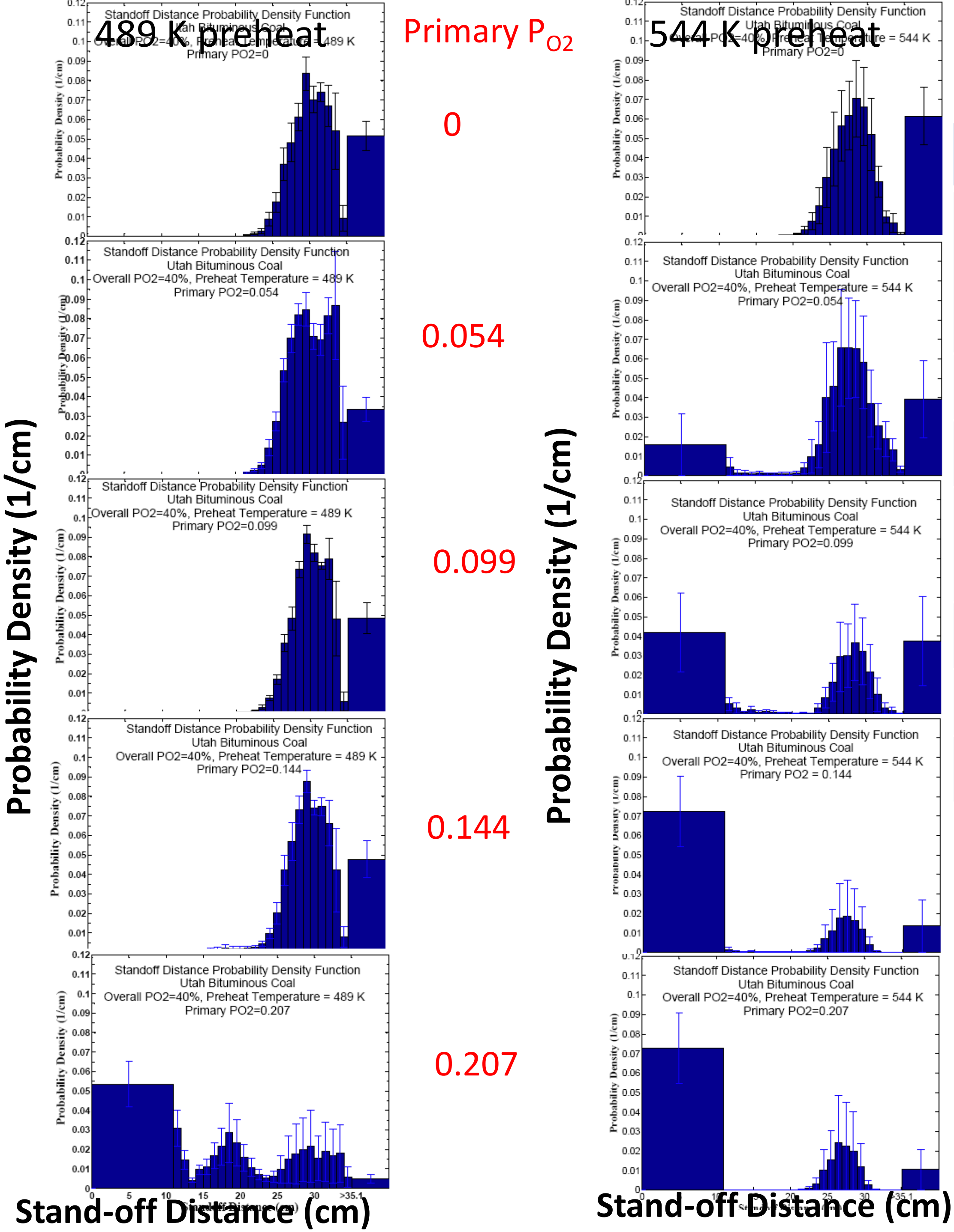
Example of PDF: O_2/CO_2 + Utah Bituminous, overall P_{O2} = 40%, secondary preheat T = 489 K, T_{wall} = 1283 K, primary P_{O2} = 0.144

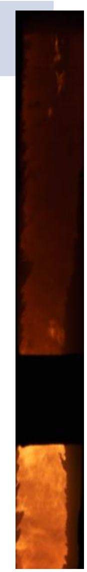


Example of PDF: O_2/CO_2 + Utah Bituminous, overall P_{O2} = 40%, secondary preheat T = 489 K, T_{wall} = 1283 K, primary P_{O2} = 0.207





Composite Plot		
Stand-off distance PDFs from 6000 images per run. 5 replicates (both left & right)		
	LEFT	RIGHT
Coal type	Utah Bituminous	
Overall PO2	40%	
Pri. Stream	O_2/CO_2 mixture	
Sec. Stream	O_2/CO_2 mixture	
Preheat	489 K	544 K



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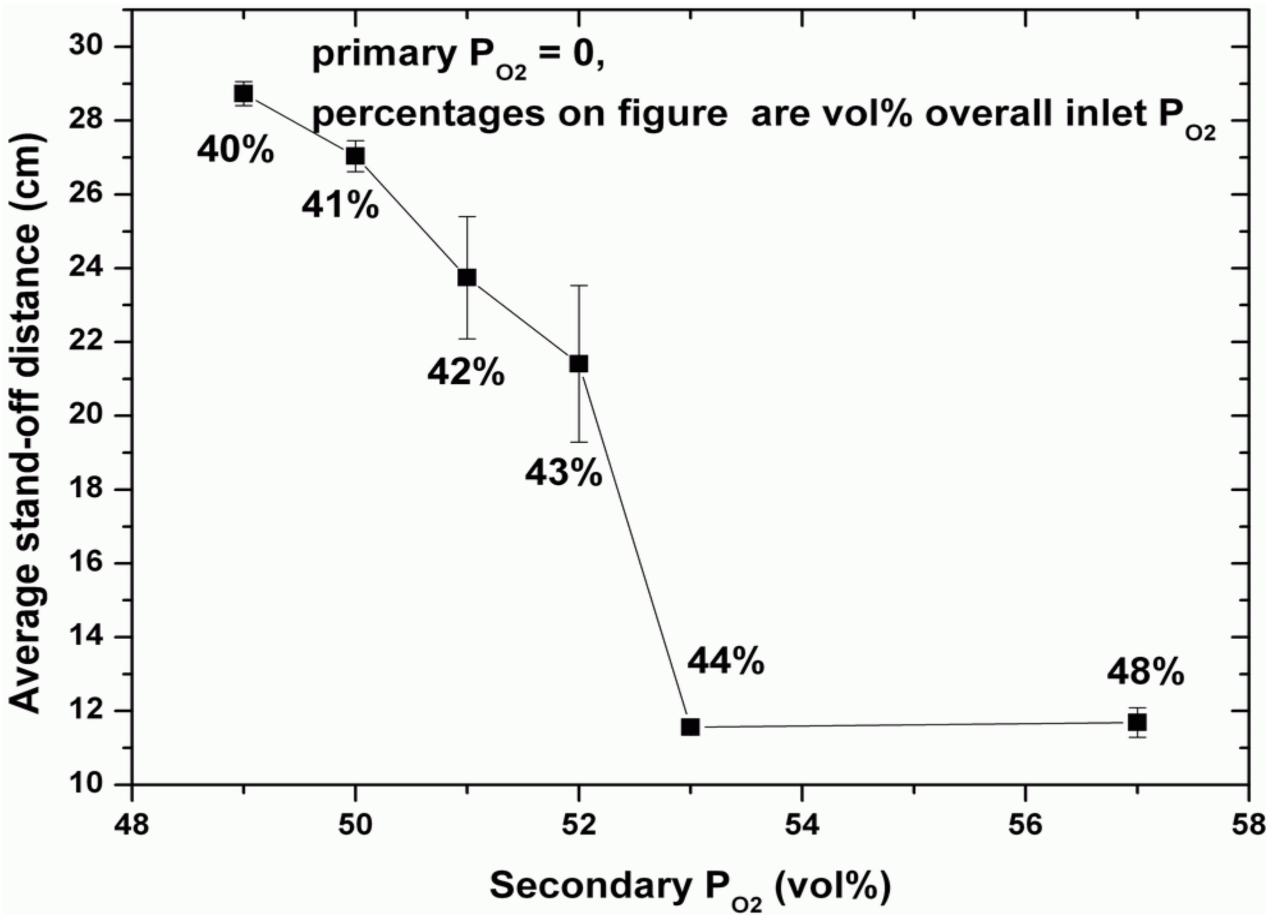
The effect of **secondary** P_{O2} on **average** stand-off distance.

The error bars presented for 40%, 44% and 48% overall inlet P_{O2} are too small to be visible.



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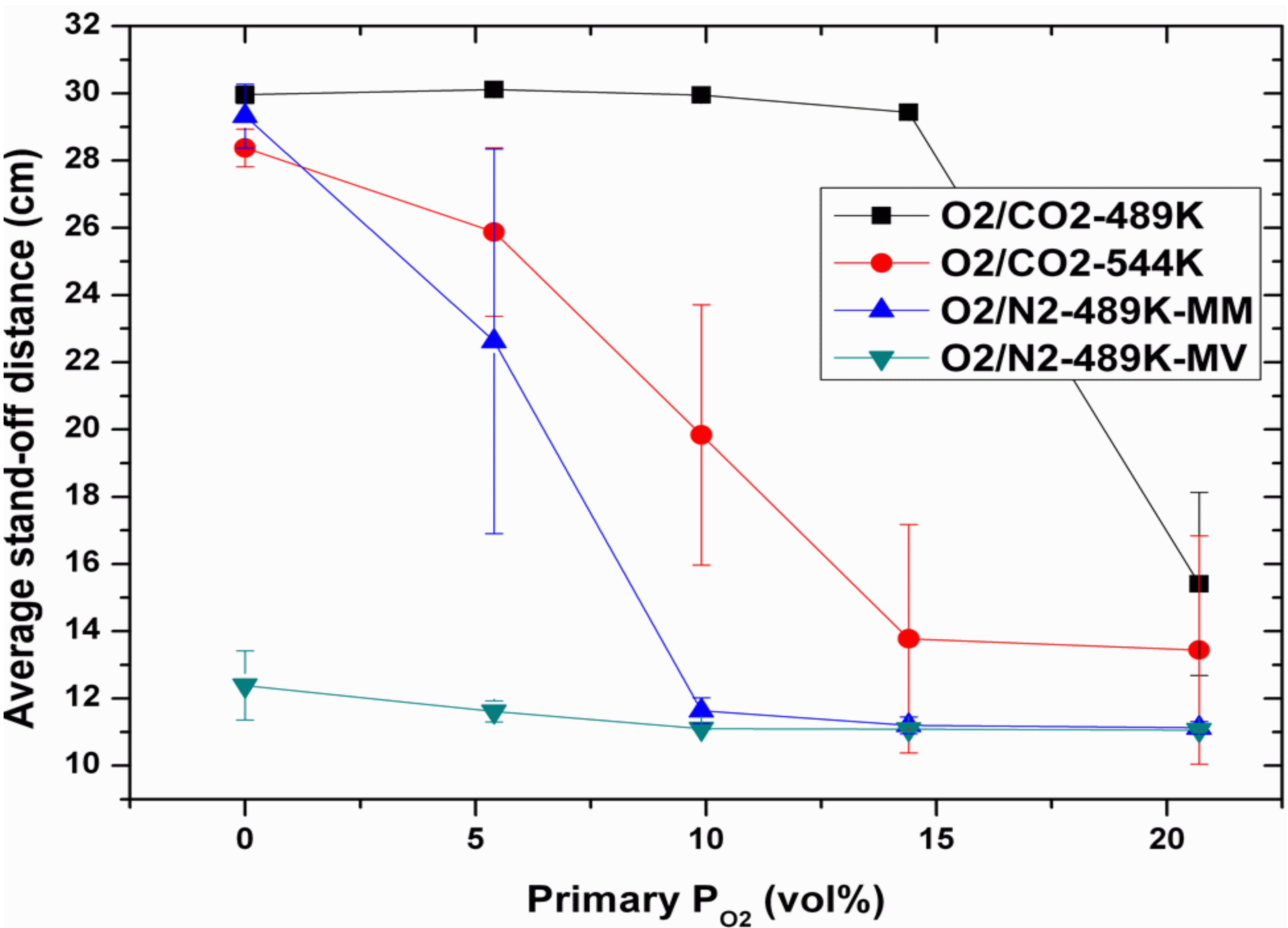
Average stand-off distance vs. primary P_{O2}: a **comparison** between **primary O_2/CO_2** mixture and **primary O_2/N_2** mixture.

The error bars presented for O_2/CO_2-489K case are too small to be visible.



2. Effect of oxy-coal combustion conditions on soot, UBC, ultra-fine particles and ash

- Two coals each burned in
  - Air
  - 27%O_2/73%CO_2
  - 32%O_2/68%CO_2
- Dilute exhaust sample
  - 0%, 1%, 2%, 3% O_2 in exhaust
  - Measure “black carbon” using photo-acoustic analyzer (PA)
  - Measure PSD of ultra-fine particulates using Scanning Mobility Particle Sizer (SMPS)
- Total ash sample
  - 0%, 1%, 2%, 3% O_2 in exhaust
  - Measure loss on ignition (LOI)
- Size segregated ash composition, 3% O_2 in exhaust only
  - Diluted, quenched, isokinetic sample
  - Low pressure impactor (LPI
    - Gravimetric PSD
    - Elemental composition by both EDS and digestion followed by ICP

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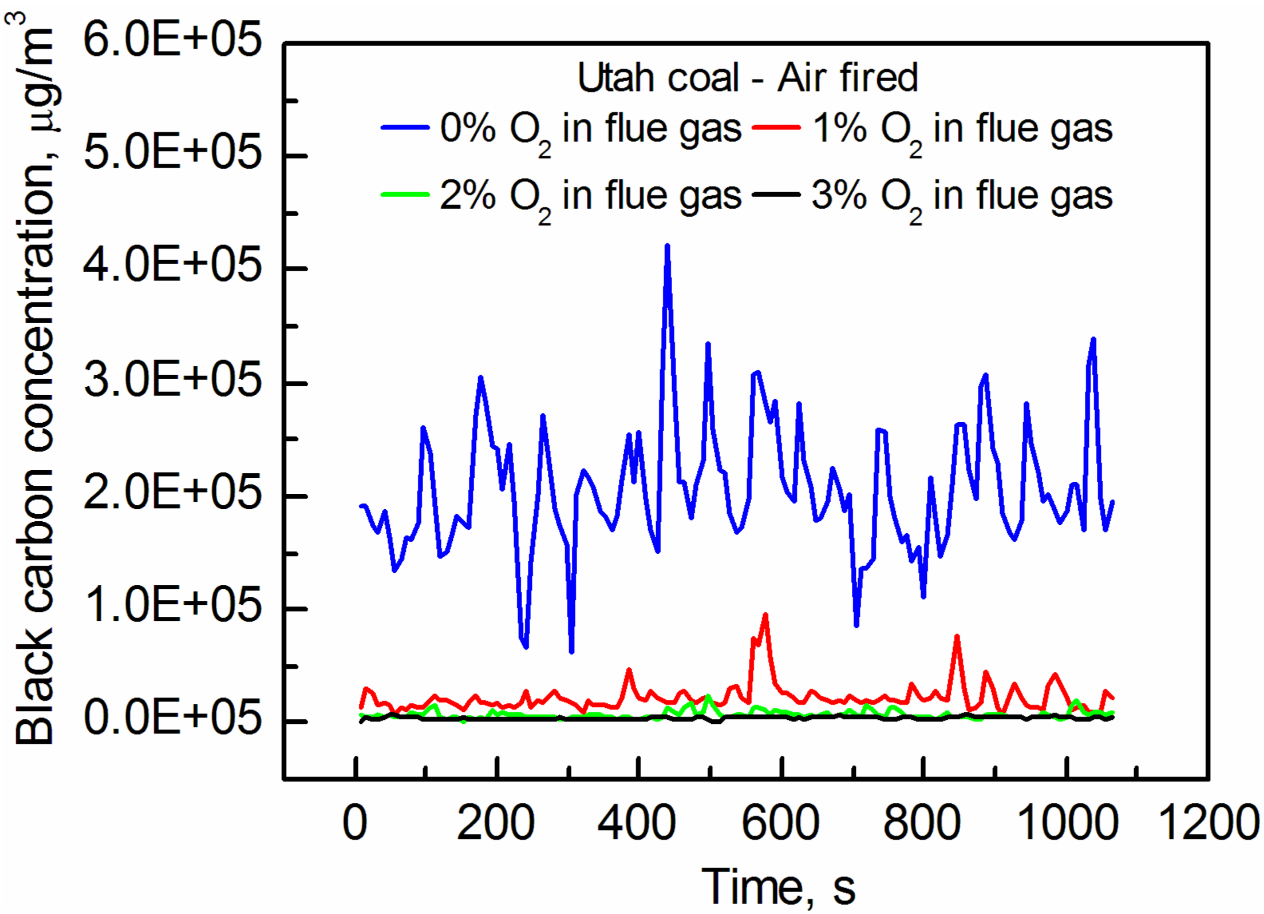
Let us first look at soot: Typical PA temporal profile

Utah air fired results: soot vs %O_2 in flue



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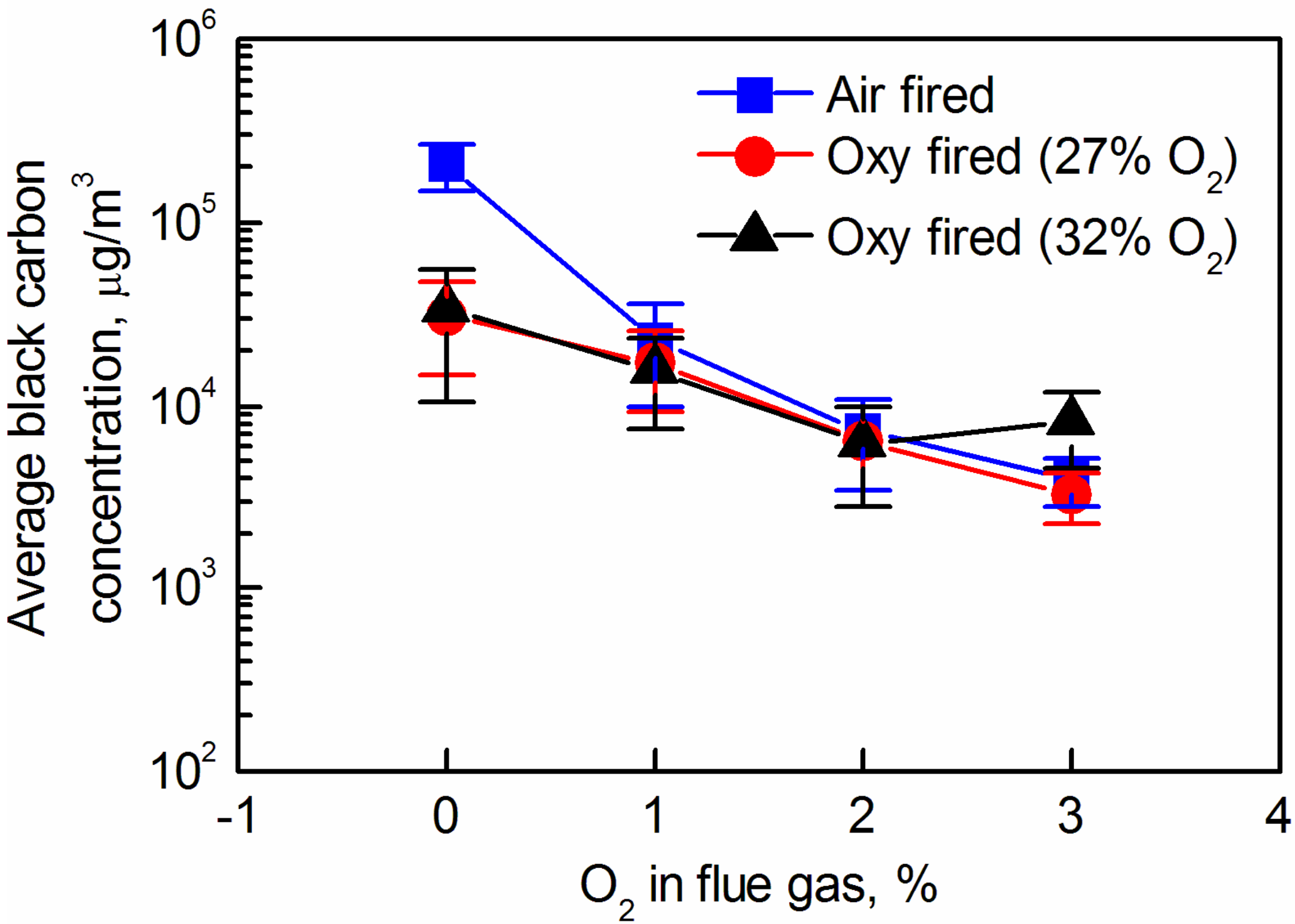
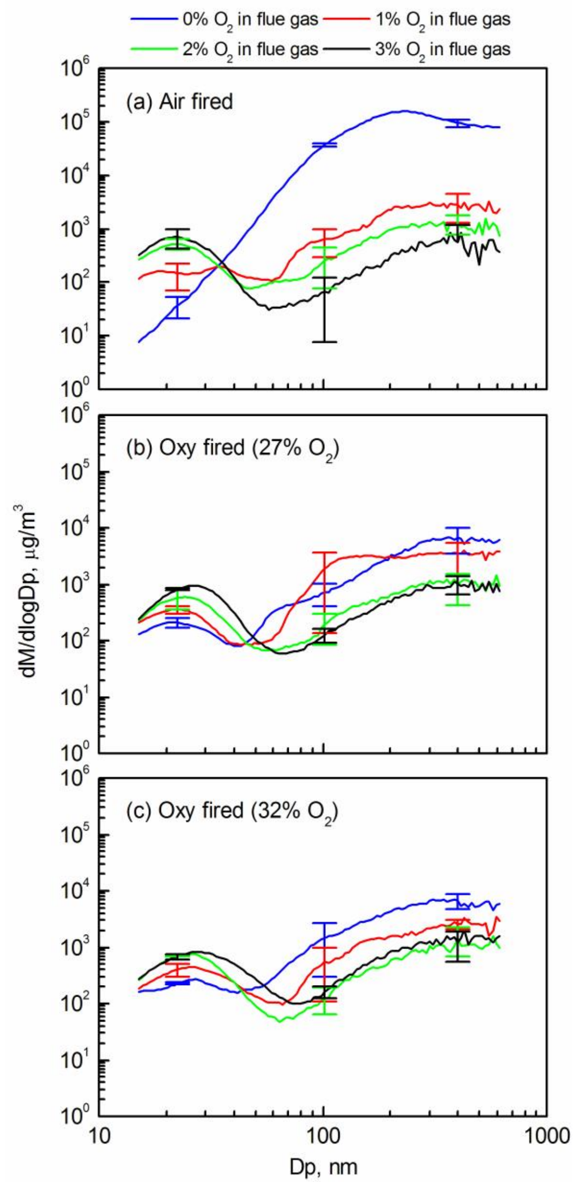
Soot: Air fired vs oxyfired

PA Utah Skyline averaged results



Ultra-fine SMPS mass distributions: Air vs oxy-firing Utah Skyline



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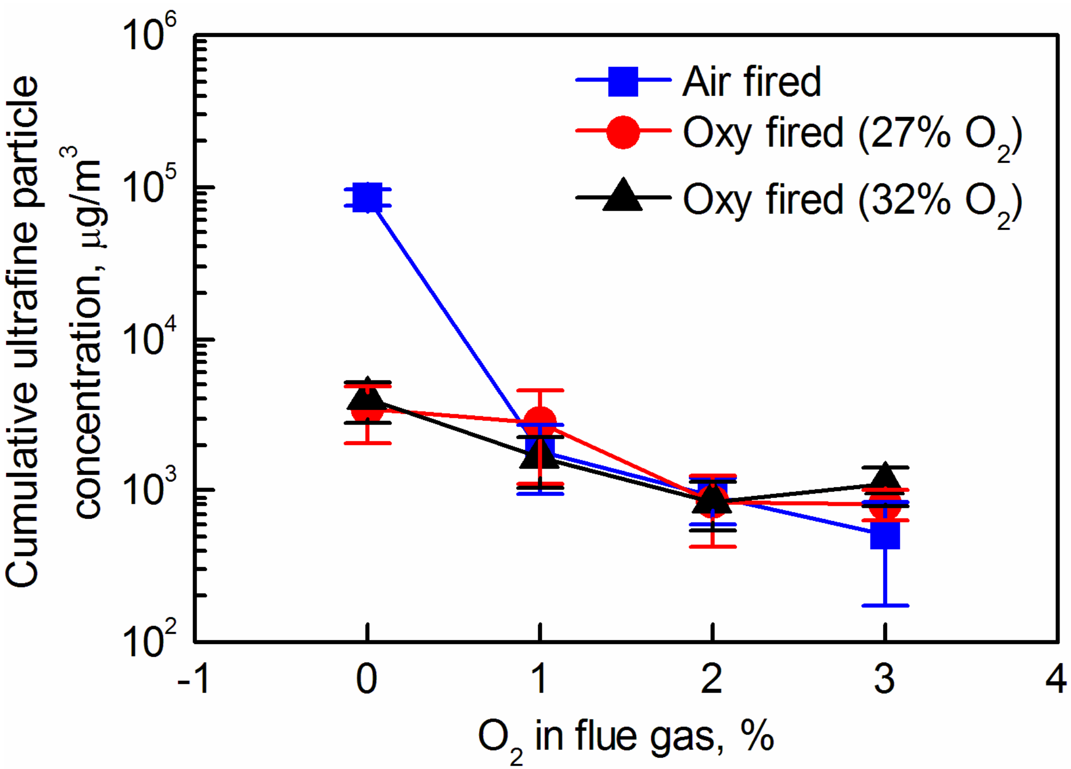
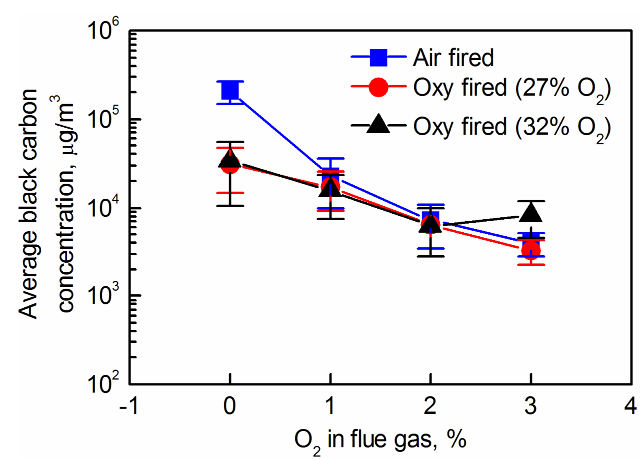
Integrated SMPS mass concentration (15-615nm)

Utah Skyline



Ultra-fines via SMPS

Soot (Black Carbon) via PA



Most of the ultra-fines are soot, and oxy-firing leads to significantly decreased soot at low SR , but slightly increased soot at high SR .

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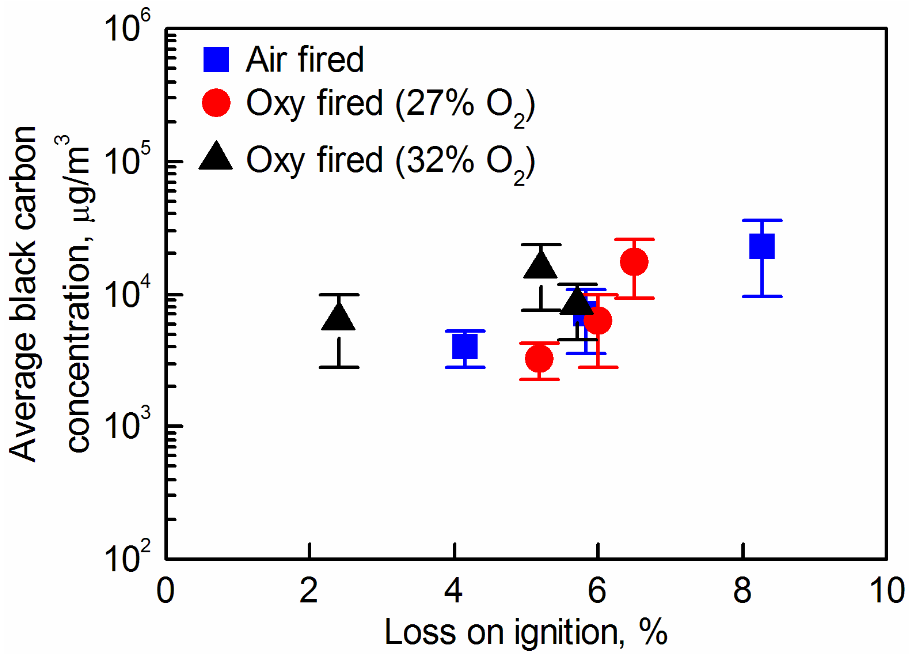
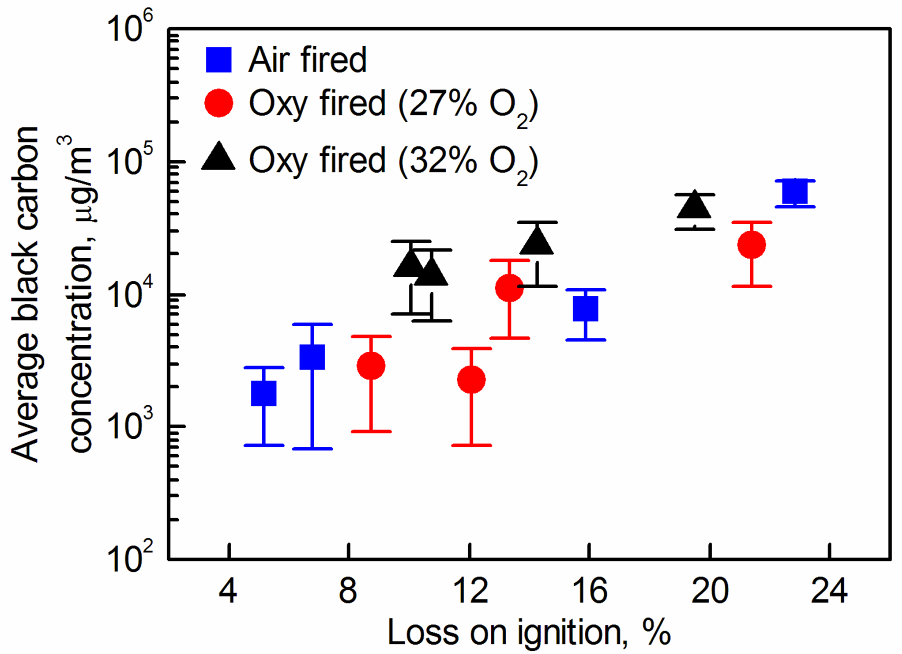
Air and oxy-firing: BC (soot) vs LOI

Utah Skyline



PRB



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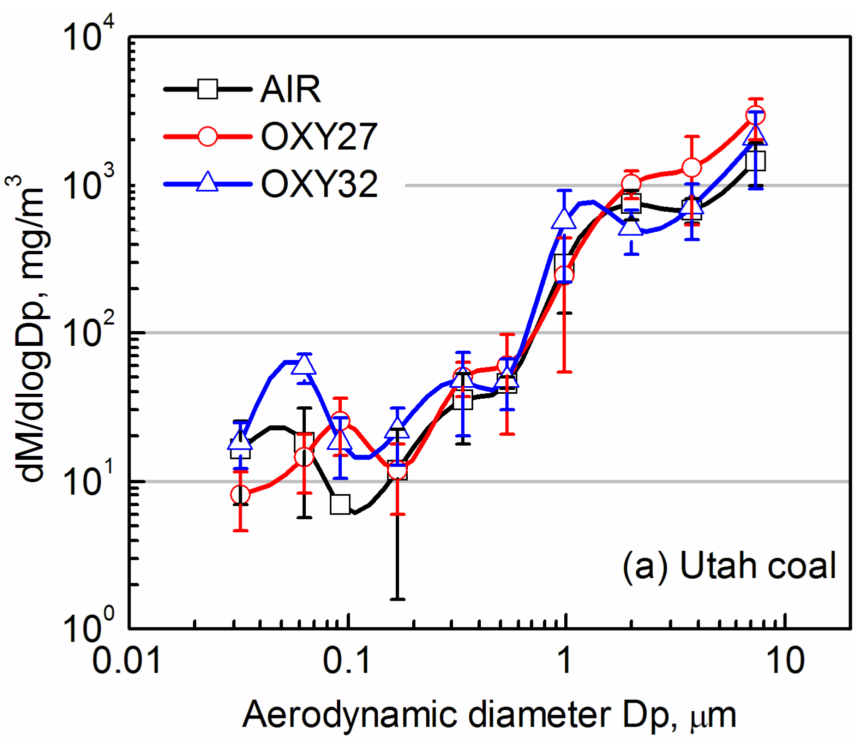
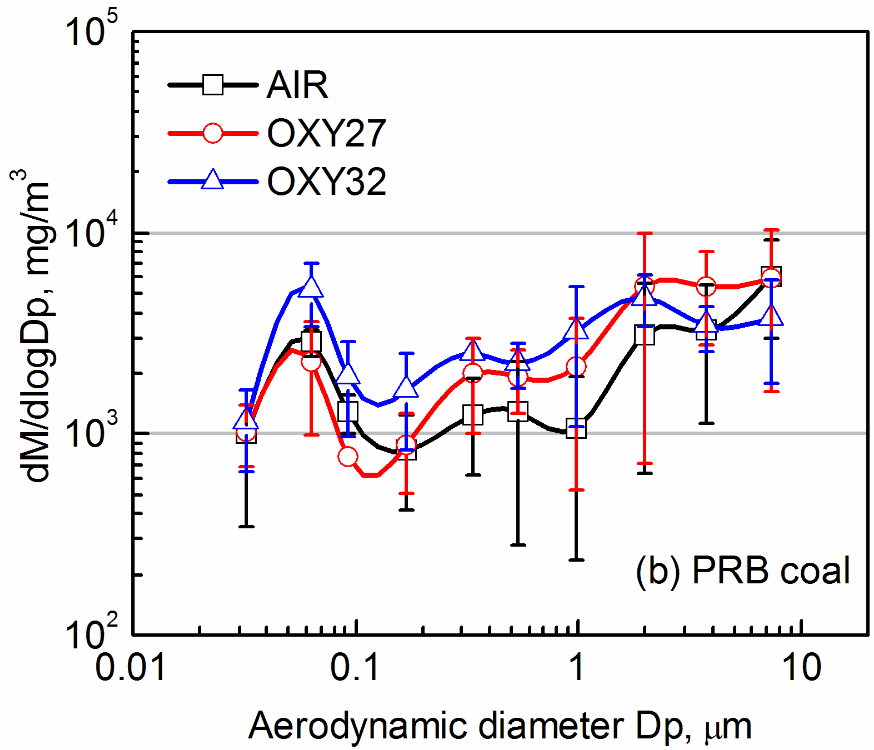
Air vs Oxy-firing, particle size distributions,

Gravimetrically obtained from LPI samples

- Utah Skyline



- PRB



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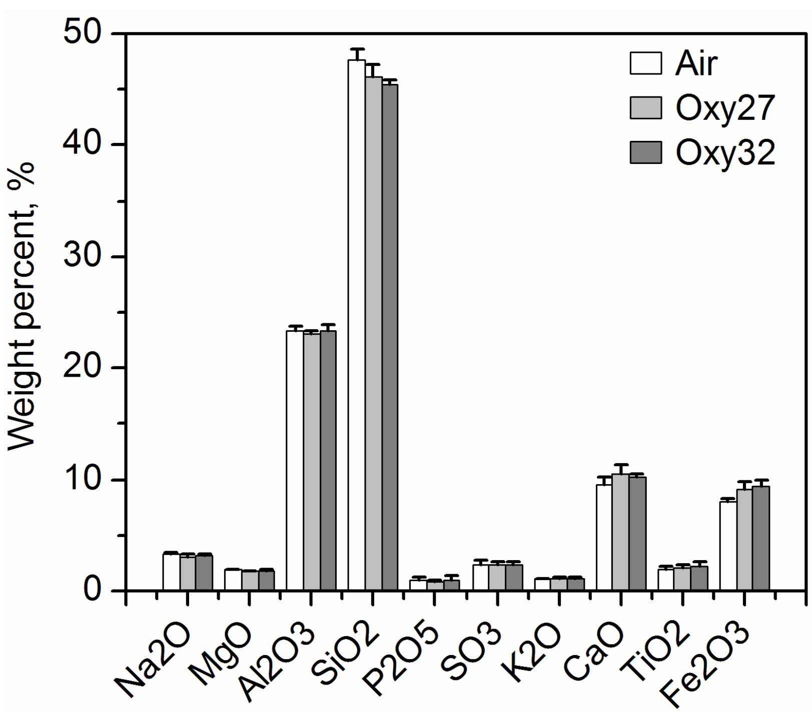
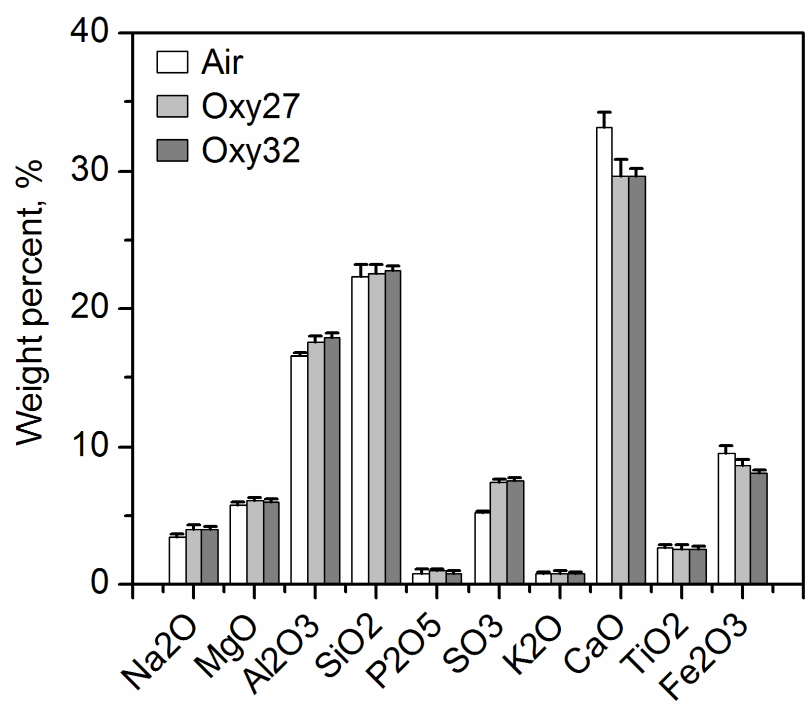
Total ash compositions

Utah Skyline Bituminous Coal



Powder River Basin Black Thunder Sub-bituminous Coal



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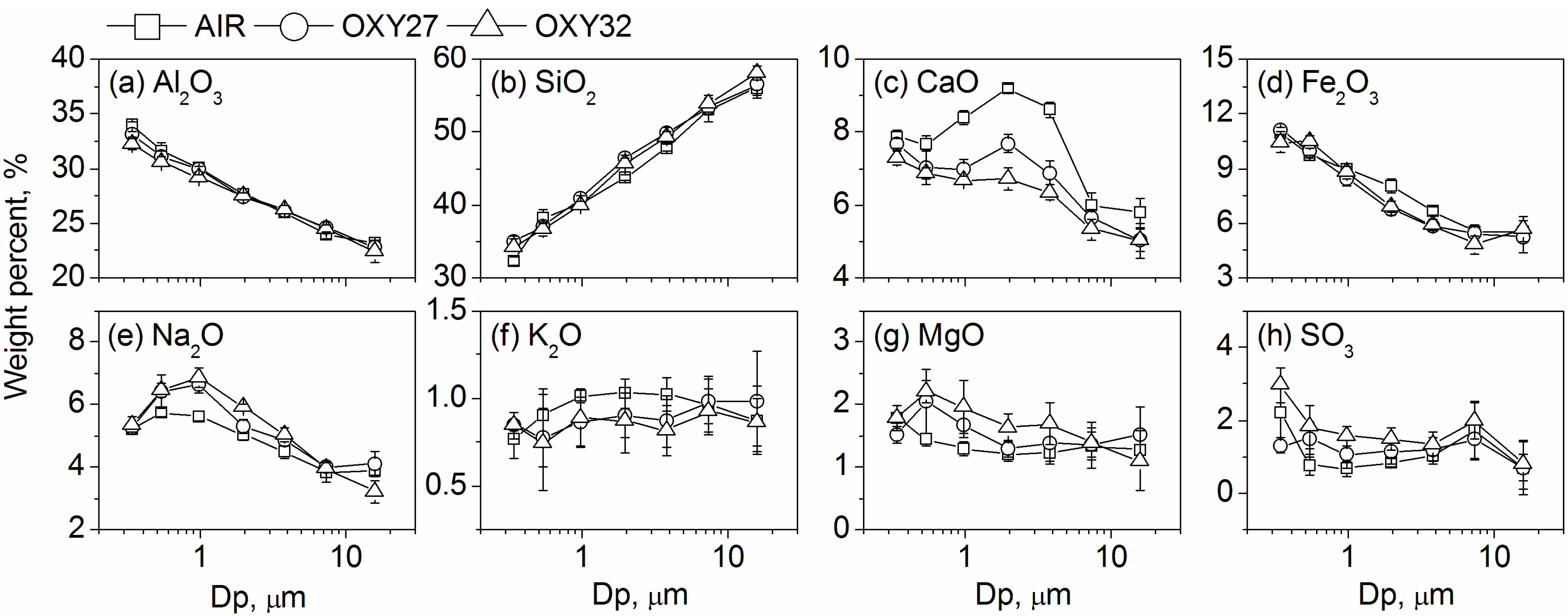
Utah Skyline: Size segregated ash compositions

EDS analsyses



Conclusions

- Ignition studies
  - Quantified flame attachment
  - Quantified effects of primary O_2, secondary O_2, secondary preheat and primary transporting fluid.
  - Provided insight into mechanism of interaction between turbulent mixing and ignition mechanisms.
  - Provided validation data with error quantification for simulations (still in progress)
- Fine particle, soot and ash studies
  - Air firing produces more soot than oxy-firing under similar adiabatic temperature and gas radiation heat flux conditions
  - At low $\%O_2$ in exhaust, ultrafine particles from coal combustion consist largely of soot. PA and SMPS measurements are consistent.
  - At 3% O_2 oxy coal firing appeared to have higher LOI than air firing, with matched adiabatic temperature or gas radiation heat flux.
  - Oxy-coal ashes enriched in SO_3 but depleted in Ca, otherwise not very different. Ca may be deposited because of lower velocities.

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Acknowledgments

- This material is based upon work supported by the Department of Energy under Award Number FC26-08NT0005015 and Co-operative Agreement Number DE-NT0005288 to Reaction Engineering International (Prime Contractor)
- Praxair Inc. for providing O_2 and CO_2 .
- Lawrence E. Bool, III, Praxair, for technical input.
- University of Utah for initial financial support.
- Technical Staff: Ryan Okerlund, Brian Nelson, David Wagner
- Undergraduate assistants: Dallin Call, Raphael Ericson, Charles German

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