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Ignition and Devolatilization of Pulverized Bituminous Coal Particles during Oxygen/Carbon Dioxide Coal Combustion

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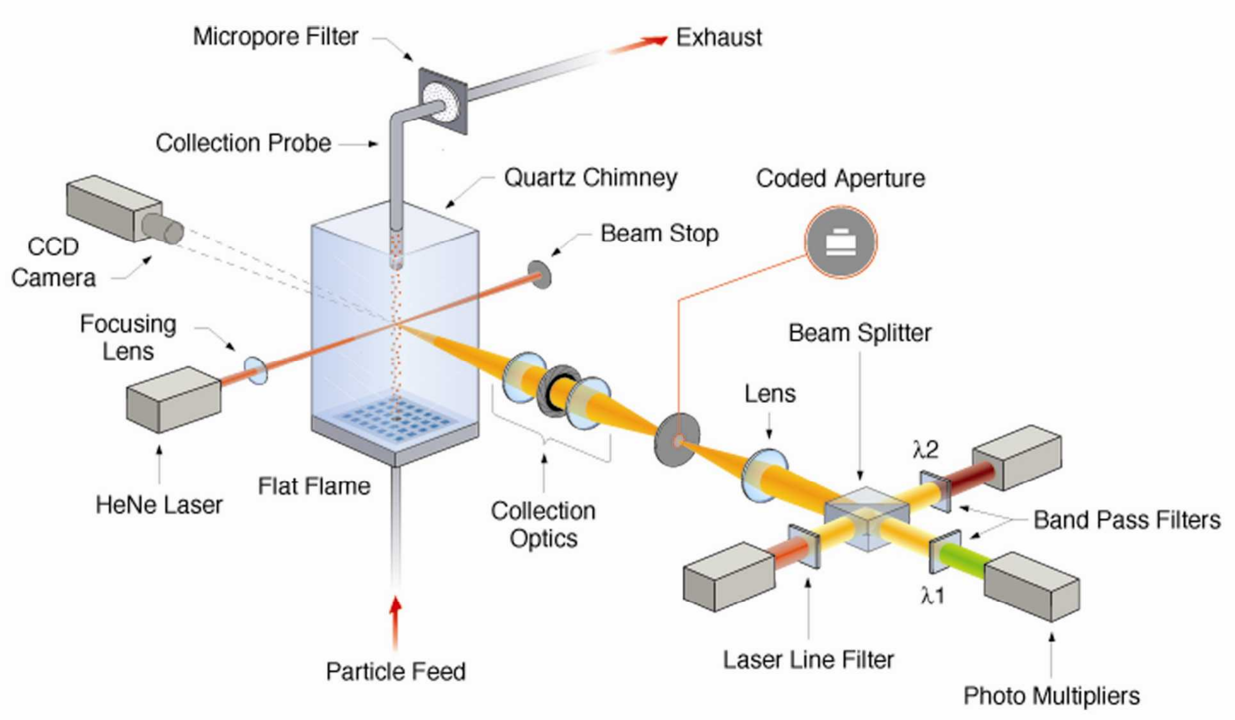
Technical Issues for Oxy-Coal Combustion (with CO_2 Recycle)

- Effect of enhanced oxygen and CO_2 on flame attachment (combustion stability, NOx formation, and burner face wear)
  - -- topic area of this presentation
- Effect of enhanced oxygen and CO_2 on char combustion and burnout
  - -- enriched-oxygen char kinetics published
  - -- CO_2 effect on kinetics measured, currently under analysis
- Effect of enhanced oxygen, CO_2, and recycled NOx on net NOx production
  - -- currently being analyzed using Sandia's Multifuel Combustor

Coal Ignition Studies

- **Historically dominated by concerns of fire safety and coal dust explosions**
  - minimum gas T for ignition of particles or cloud (irrespective of ignition delay time)
  - gas T for ignition decreases with increasing O_2 concentration
  - highly variable ignition T found depending on method of dust cloud preparation and injection
  - single-particle studies recommended for consistency
- **Few studies on pc ignition time in high temperature environment**
  - relevant criteria for burner operation
  - ignition times on order of 10 ms

Experimental Setup: Combustion-Driven Optical Entrained Flow Reactor

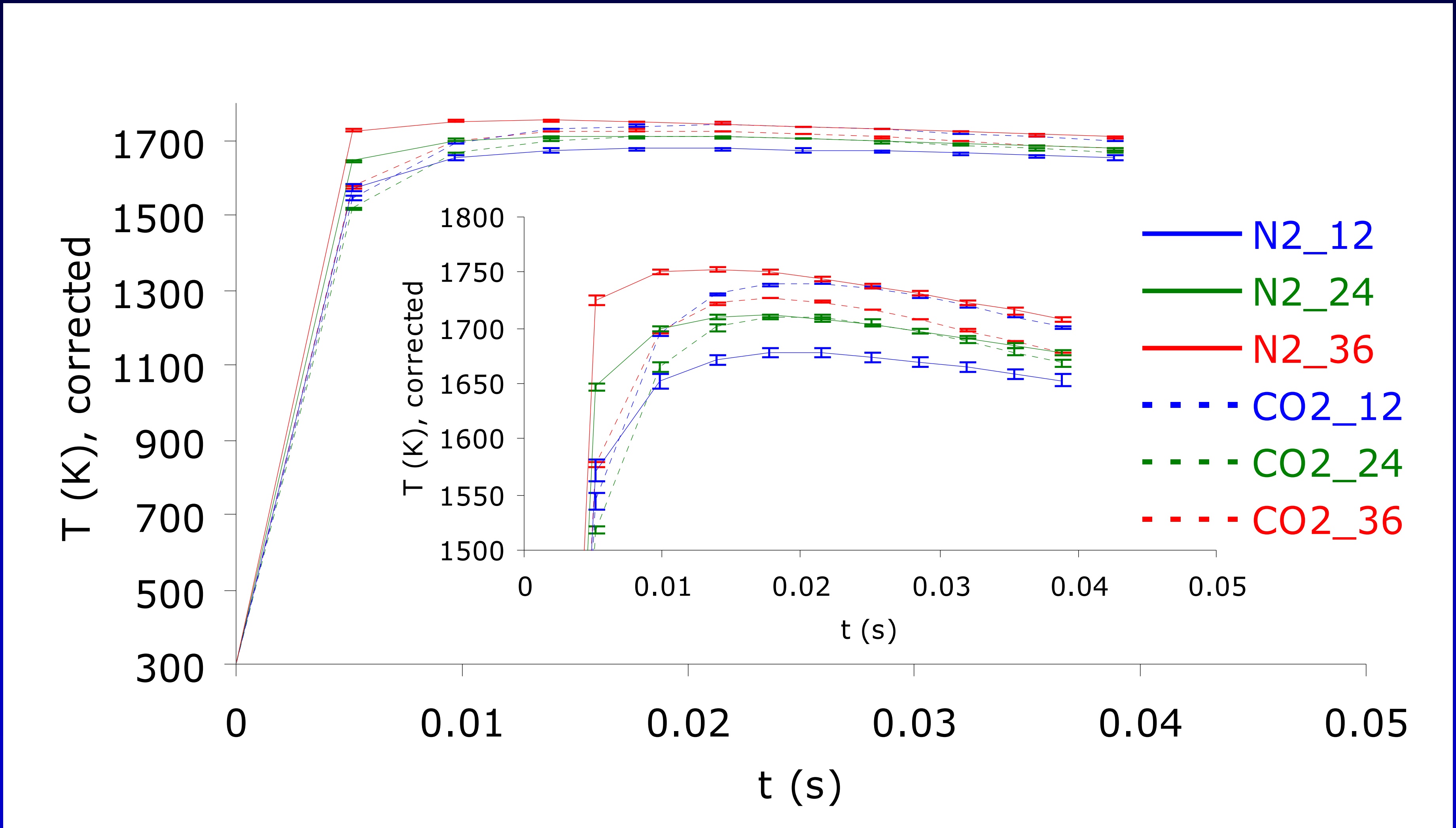


- 1 atm
- compact, diffusion-flamelet burner
- coal particles introduced along centerline
- quartz chimney
- coded-aperture, 2-color pyrometry diagnostic for char size, T, and velocity
- laser-triggered ICCD for single particle imaging

EFR Gas Compositions Investigated

Composition (%)	Operating Condition					
	N_2_12	N_2_24	N_2_36	CO_2_12	CO_2_24	CO_2_36
O_2	12.0	24.0	36.0	12.0	24.0	36.0
N_2	70.0	58.0	45.9	0.0	0.0	0.0
CO_2	4.0	4.0	4.1	74.0	62.0	50.0
H_2O	14.0	14.0	14.0	14.0	14.0	14.0

Gas Temperature Profiles



About the Gas Temperatures

- **CO_2 has a significantly greater (1.6 X) molar specific heat than nitrogen (and oxygen)**
- **For combustion in CO_2 environments, flame temperatures are lower (for a given initial O_2 concentration)**
  - CH_4/air adiabatic flame T = 2226 K
  - CH_4/O_2-CO_2 (21% O_2) adiabatic flame T = 1783 K
  - CH_4/O_2-CO_2 (32% O_2) adiabatic flame T = 2226 K
- **This study addresses effect of O_2 and CO_2 on ignition time, *independent of global flame effects associated with flame T* (i.e., we're focusing on *microscale* effects)**

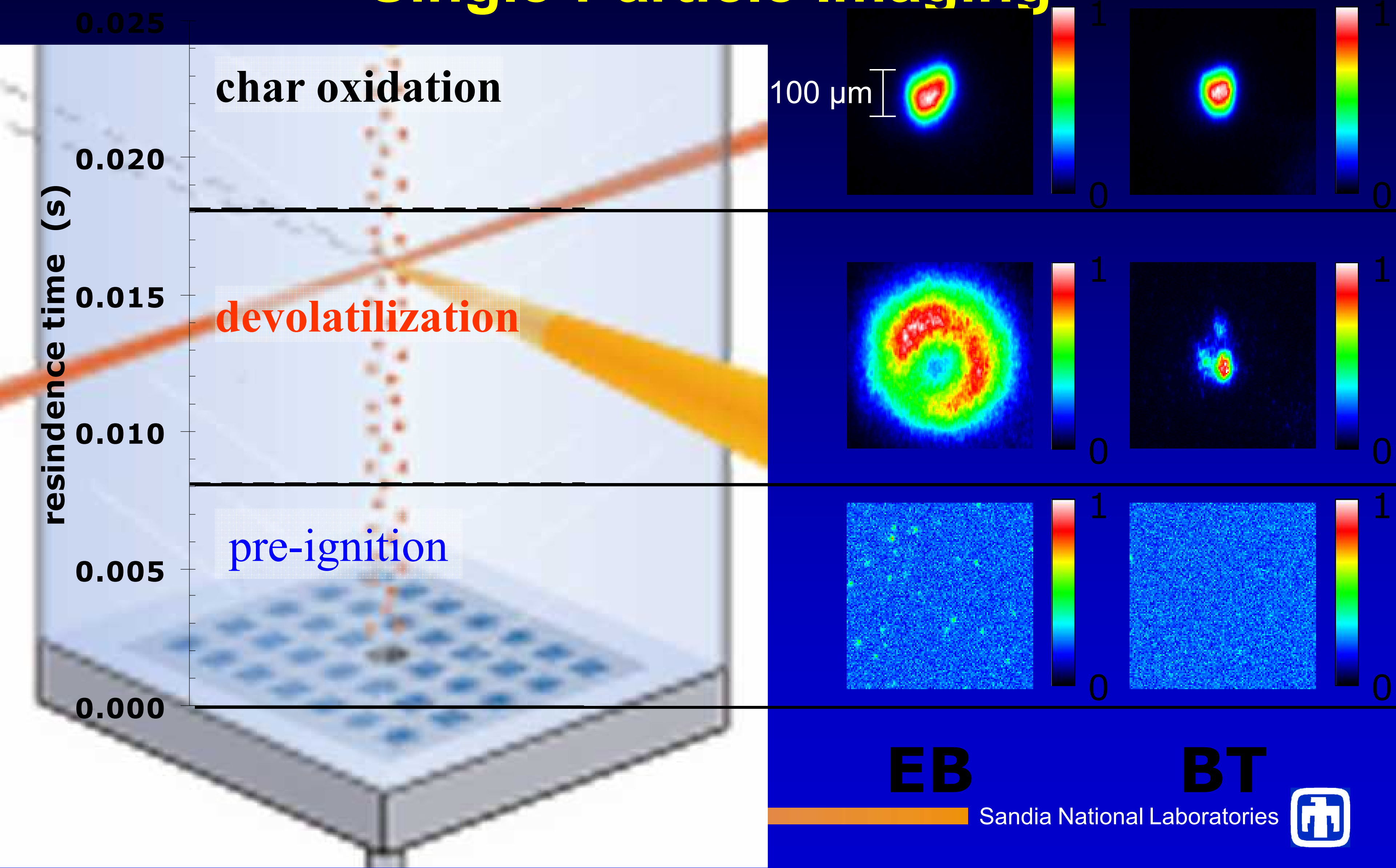
Coals Investigated

	Coal Type			
	Pittsburgh Bailey		Black Thunder	
Proximate	wt%, as rec'd	wt% dry	wt%, as rec'd	wt% dry
moisture	1.43		10.80	
ash	6.91	7.01	5.01	5.62
volatile	35.38	35.89	40.41	45.30
fixed C	56.28	57.10	43.78	49.08
Ultimate	wt% dry	wt% DAF[a]	wt% dry	wt% DAF[a]
C	77.20	82.93	60.90	64.11
H	5.19	5.58	5.18	5.45
O (by diff)	7.15	7.68	27.60	29.05
N	1.52	1.63	0.87	0.92
S	2.03	2.18	0.44	0.46

[a] dry, ash-free

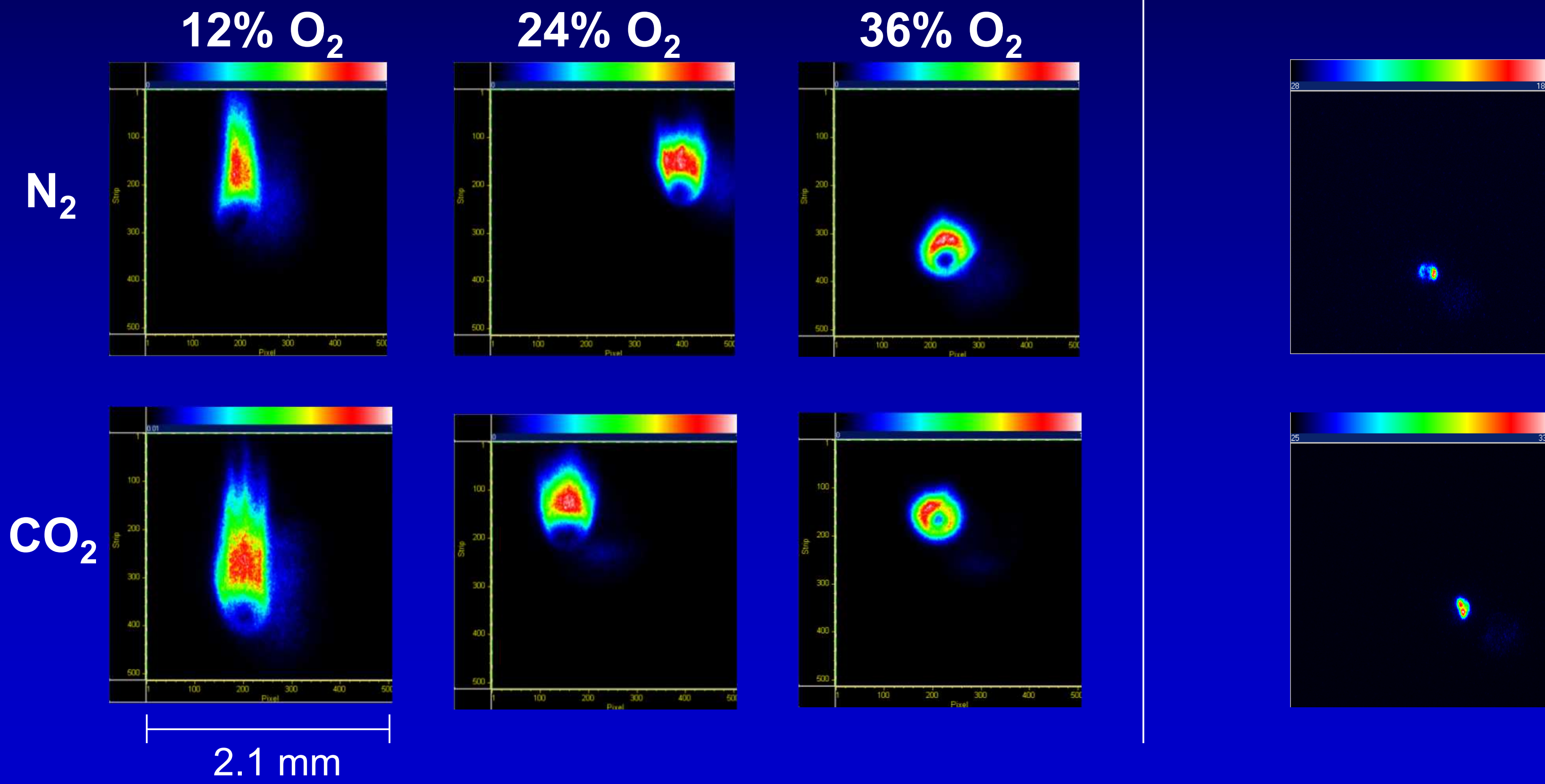
Both coals were sieved to a 75–106 μm size fraction

Single-Particle Imaging

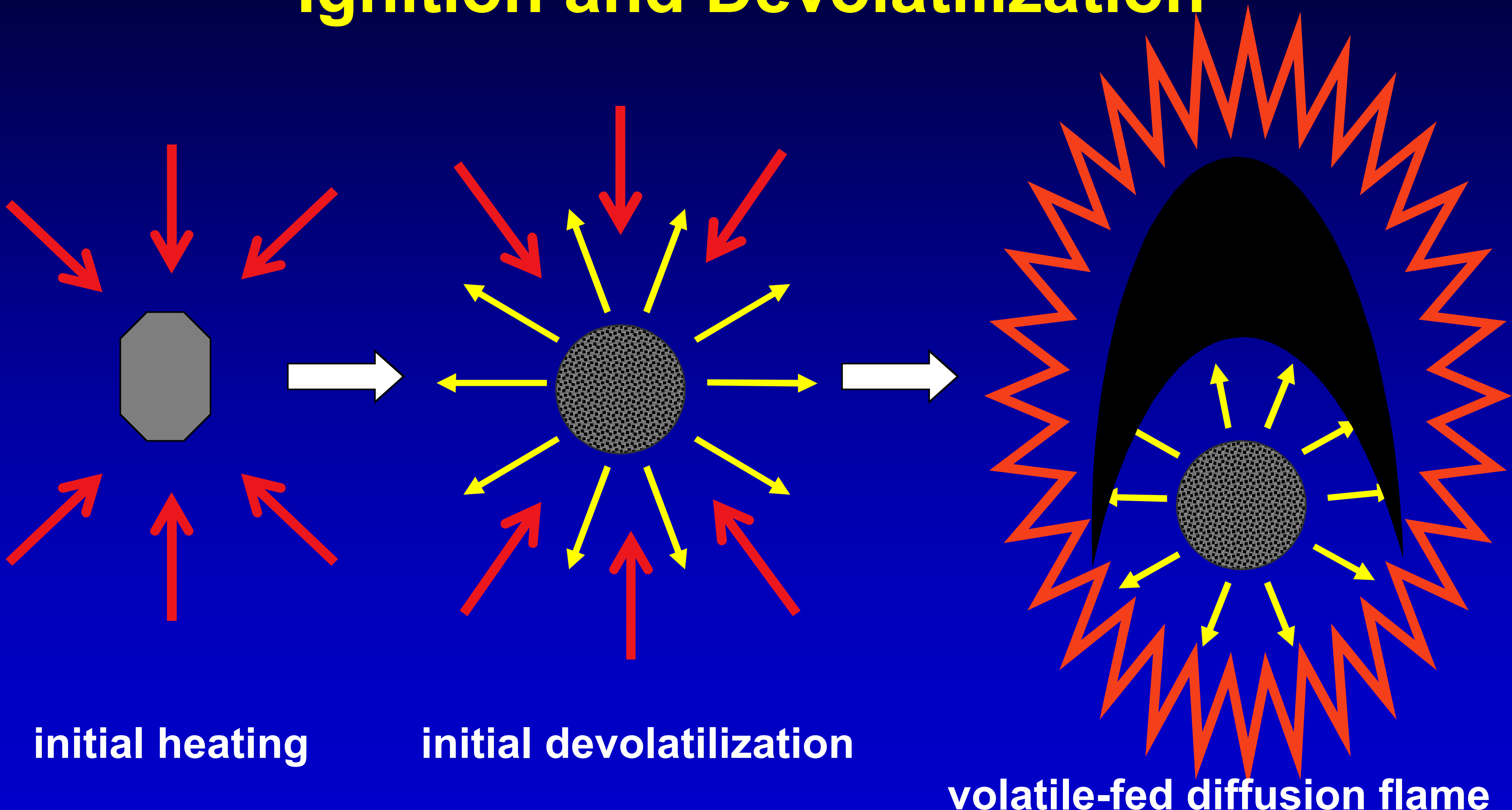


Effect of O_2 and N_2/CO_2 on Devolatilization

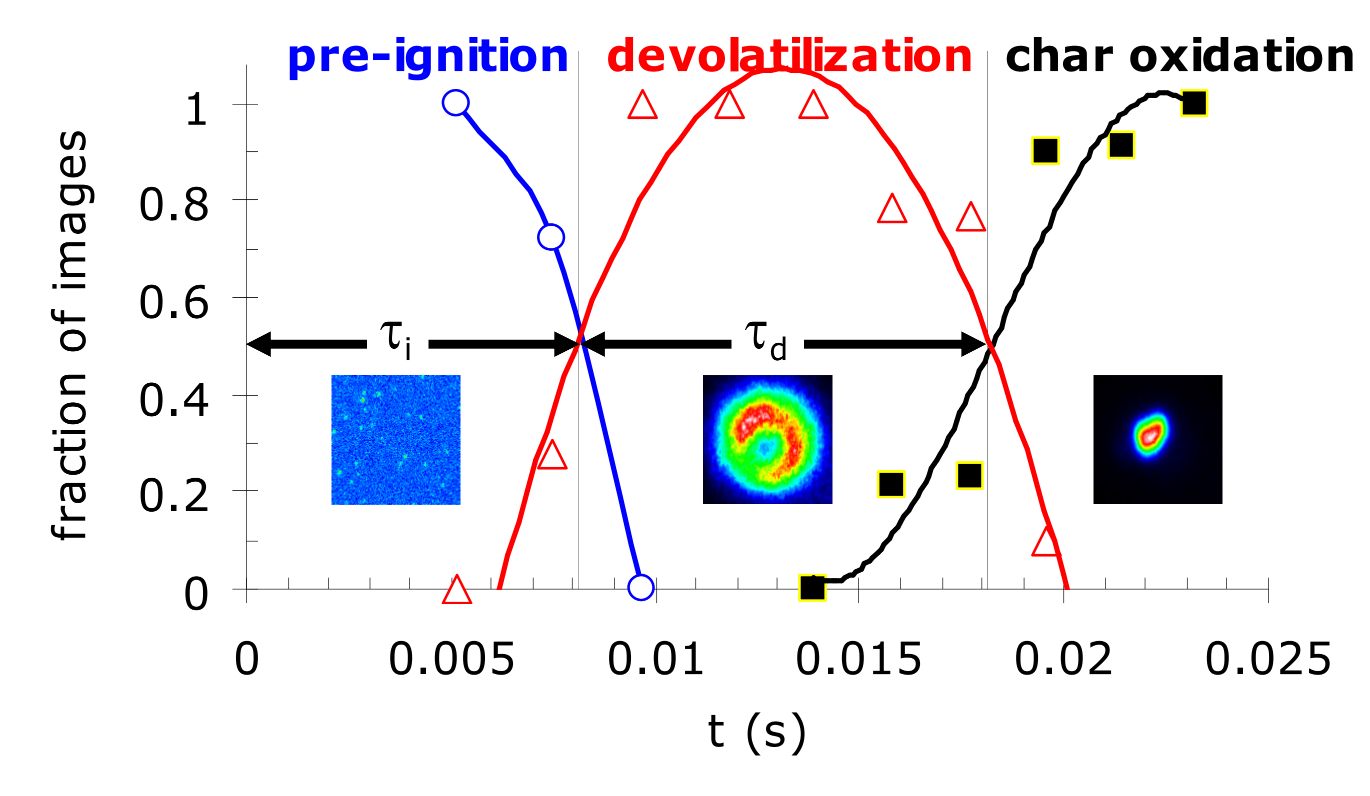
Pittsburgh Coal | Black Thunder Coal



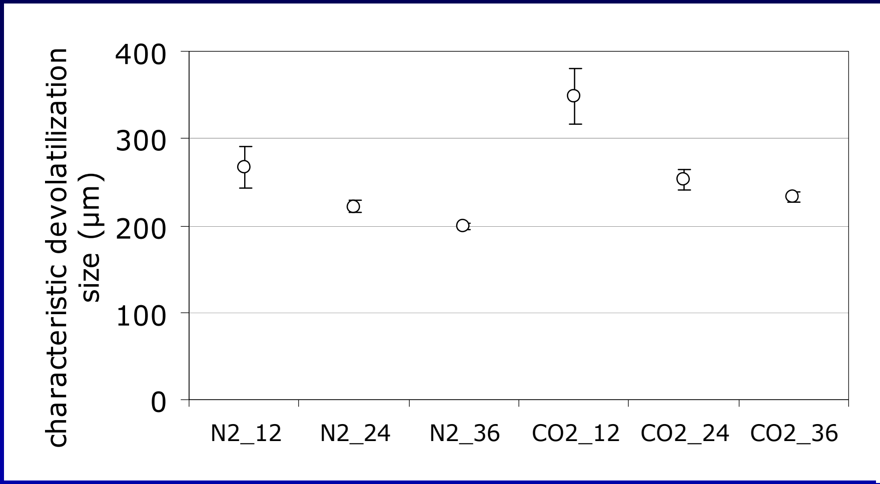
Conceptual Model of Single-Particle Ignition and Devolatilization



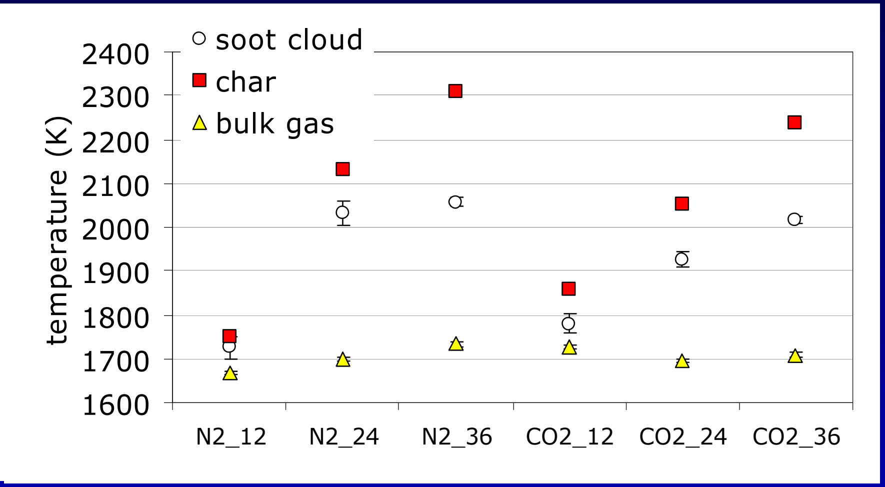
Quantifying Image Data: Characteristic Zones



Characteristic Soot Cloud Size and Temperature: Pittsburgh Coal

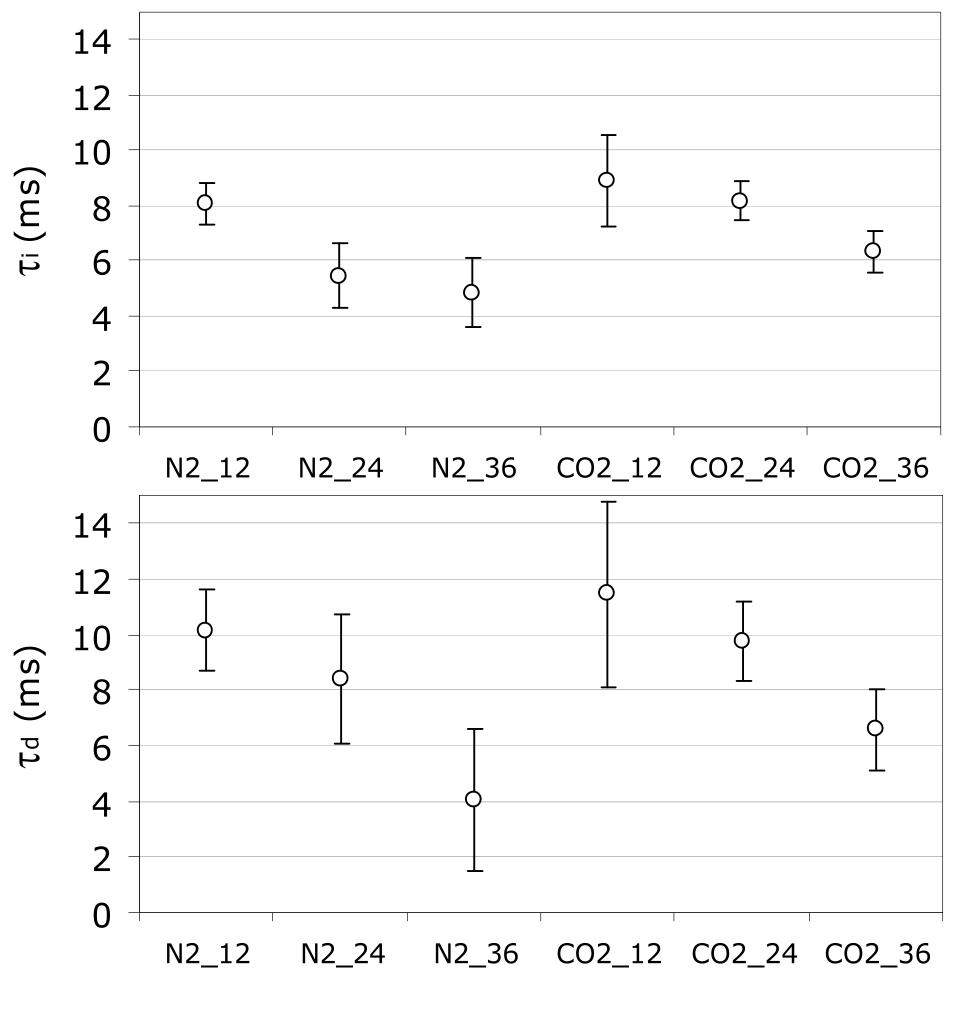


soot cloud size

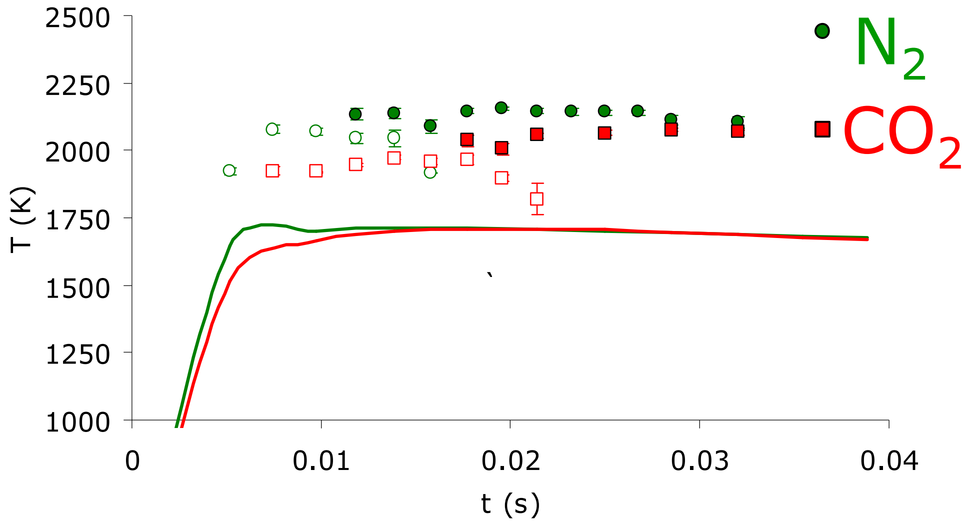


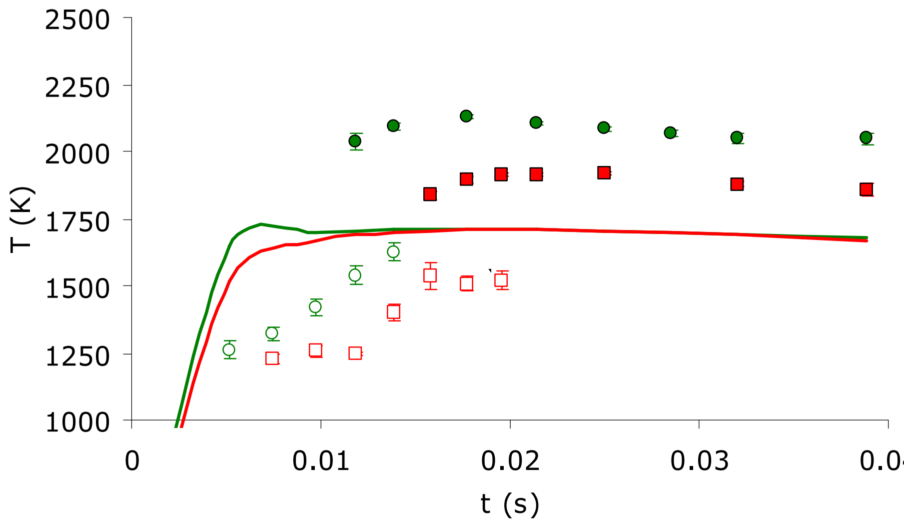
soot, gas, and char comb. temperatures

Ignition and Devolatilization Times: Pittsburgh Coal



Mean Temperatures: 24% O_2





Pittsburgh coal **Black Thunder coal**

Understanding the Effects of O_2 and CO_2: Particle Ignition

- **Initial particle heat-up:**

$$\frac{dT_p}{dt} = \frac{-3}{C_{p,p}\rho_p r_p}\left[\varepsilon\sigma\left(T_p^4 - T_w^4\right) + h\left(T_p - T_g\right)\right]$$

- **h = k*Nu/d ; Nu ~ 2 ; $k_{CO2} \sim k_{N2}$**
- ***Initial heat-up should be independent of O_2 and CO_2***
- **Therefore, particle ignition differences due to homogeneous ignition process of volatiles in hot gas; dependent variables are:**
  - reactivity of local mixture (O_2 effect)
  - combustion heat release
  - ρC_p of local gas mixture (1.7 X larger for CO_2)

Understanding the Effects of O_2 and CO_2: Devolatilization Time

- From droplet combustion theory:

$$\dot{m} = 4\pi r_s \left(\rho_s D_v\right) \ln\left(1 + B\right)$$

where the Spalding transfer number is

$$B = \left[C_{p,v}\left(T_\infty - T_s\right) + \left(Y_{o,\infty} / OF\right) h_c\right] / h_v$$

- O_2 concentration feeds directly into Spalding transfer number
- mass consumption rate is lower in CO_2 because $D_{v,CO2} < D_{v,N2}$ (e.g., $D_{CH4,CO2} = 0.8 * D_{CH4,N2}$)

Conclusions

- Separate from the macroscale effects associated with overall flame T and radiant heat transfer, both O_2 and CO_2 concentrations affect single-particle ignition and devolatilization processes
- Oxygen effects are much stronger than CO_2 effects
- O_2 affects particle ignition because of its influence on gas mixture reactivity and affects devolatilization flame size and devolatilization time because of increased O_2 diffusional flux
- CO_2 affects ignition because of its high ρC_p and affects devolatilization flame because of decreased diffusion of fuel vapor
- Relative to air, microscale O_2/CO_2 effects on ignition and devolatilization approximately cancel each other out for 30% O_2 in CO_2 (similar to macroscale canceling)

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End of Presentation

Questions?