Oxy-Fuel Coal Combustion

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Options for Clean Coal

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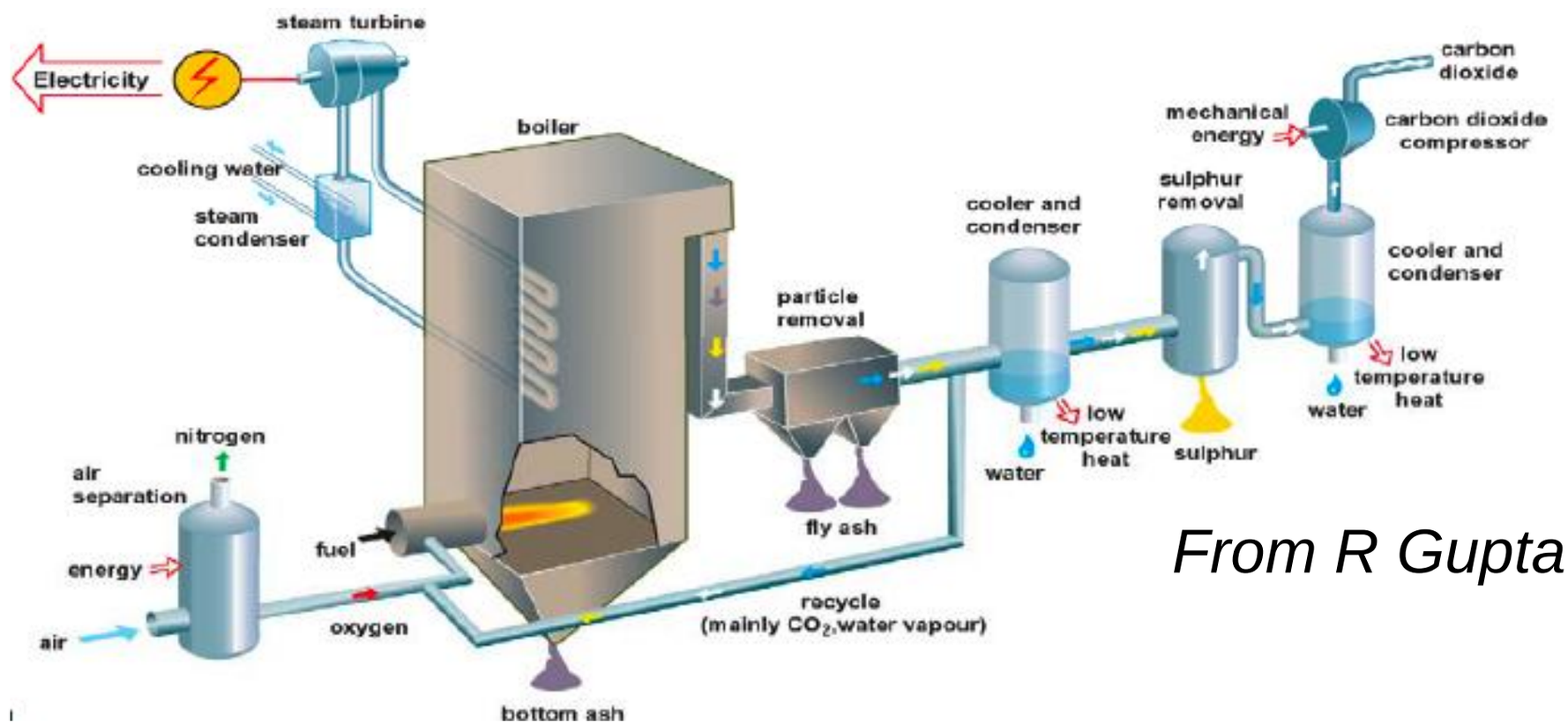
- Three front runners:
  - **Oxygen combustion (Oxyfuel)**
    - Concentrated CO_2 in products
  - **Amine (or others) scrubbing** for new or existing plants
    - Extracts the CO_2 from the flue gas using a regenerable sorbent-catalyst such as momoethanolamine (or MEA)
  - **Integrated Gasification Combined Cycle** (**IGCC)**
    - Also concentrates CO_2
    - Attractive approach, but challenges include complexity of operation
- "*Some current studies show oxygen combustion as the least costly while others lean toward IGCC, indicating that the jury is still out*." (Williams et al., BR-1779, 2006)

What is oxyfuel combustion?

- Oxyfuel
  - Pure oxygen as oxidizer (often diluted with flue gas)
  - Reduces or eliminates NOx (no Nitrogen in oxidizer flow)
- Increases CO_2 concentration
  - Easier to recover

Could be used in retrofit coal plants



From R Gupta

Progress of Project

- Literature Reviewed
- Radiation analysis in a pilot scale oxy-fuel boiler firing natural gas and coal in Jupiter's pilot scale burner
- Construction of particle burner
- Initial combustion results

Radiation Measurements - Motivation

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- Radiative Heat Transfer
  - Dominant heat transfer mode in boiler furnace
  - Non-gray body behavior (spectral dependence)

- Temperature Measurements in Oxy-Fuel Boilers
  - Pilot scale
  - Above 3,000 K in Jupiter burner
  - Challenging to measure

Objectives

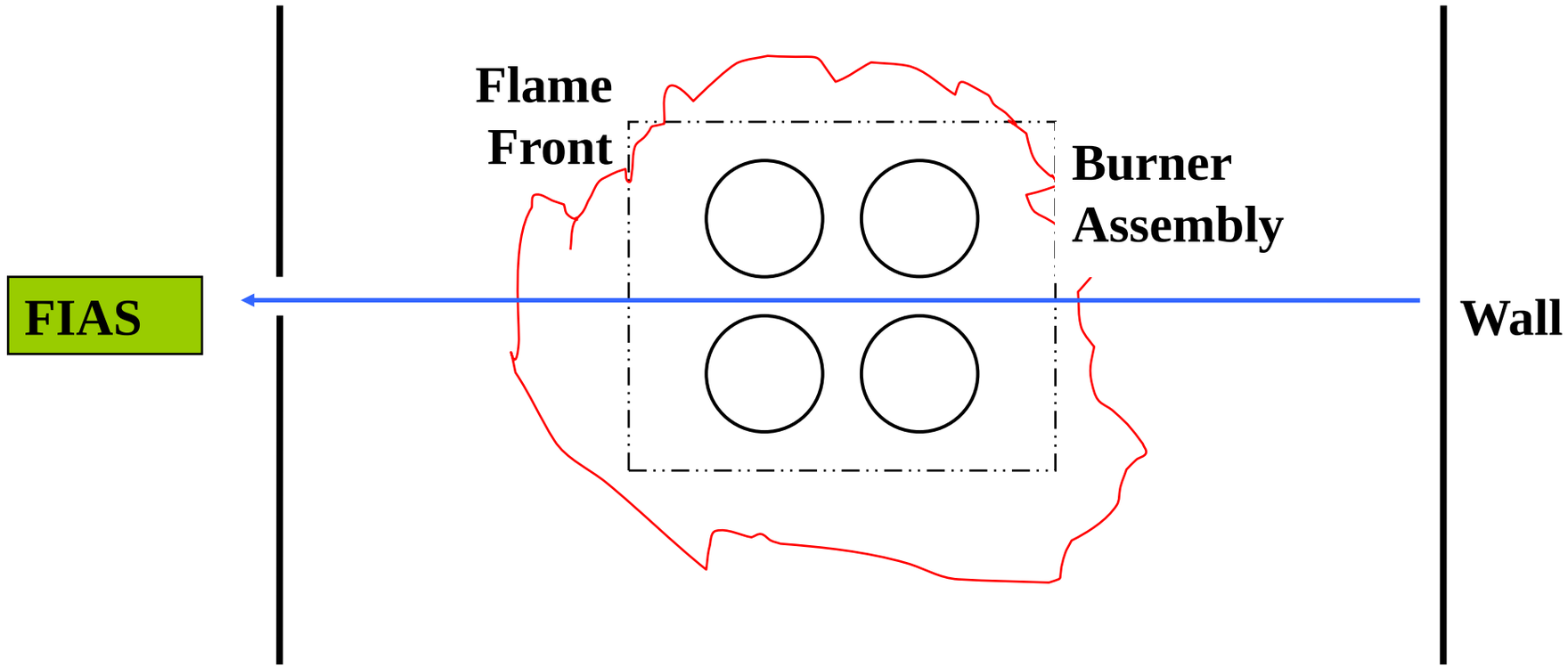
- Measure spectral radiation intensities of a pilot-scale oxy-fuel boiler at various locations (by Jupiter engineers)
- Analyze measured radiation data
- Estimate temperate profile at one cross-section of the boiler furnace using inverse radiation interpretation

Experimental Methods

- The Pilot Scale Boiler
  - Doosan Backcock 80 MBtu/hr boiler
  - Four Maxson 10 MBtu/hr
  - Total heating rate during tests: < 30 MBtu/hr
- Test Matrix
  - HT oxy-natural gas without CO_2 recycling
  - HT oxy-natural gas with CO_2 recycling (blanket)
  - LT oxy-natural gas with CO_2 recycling (synthetic air)
  - Air firing natural gas
  - HT oxy-coal without CO_2 recycling
- Fast Infrared Array Spectrometer (FIAS)
  - Portable
  - Staggered PbSe linear array sensor cooled by TEC
  - 160 wavelengths from 1.4 to 4.8 υm
  - Scan frequency: 6,250 Hz
  - Acquisition frequency: 1,320 Hz

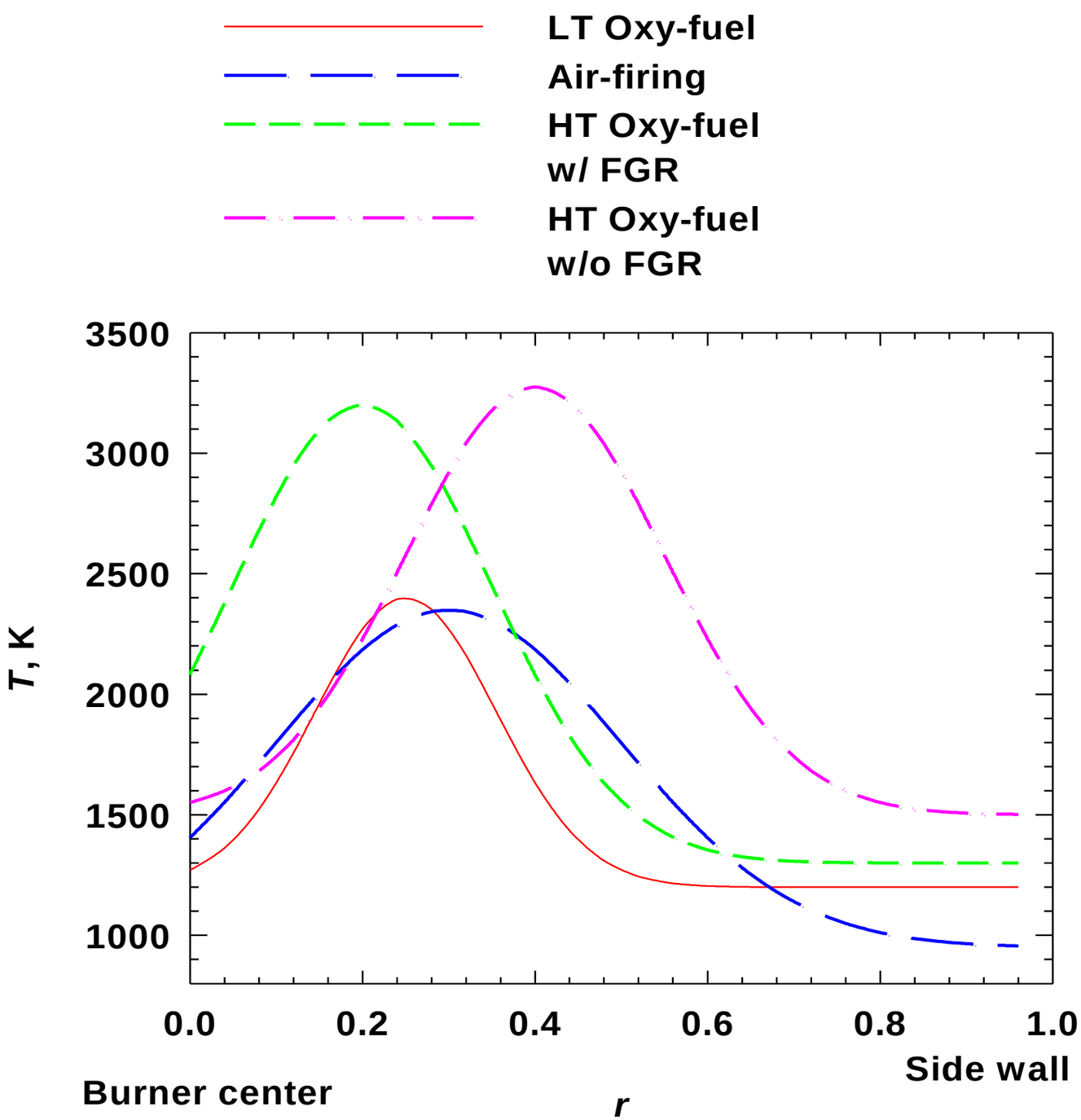
From Jupiter Oxygen

Temperature Estimate



Arrangement of spectral radiation intensity measurements

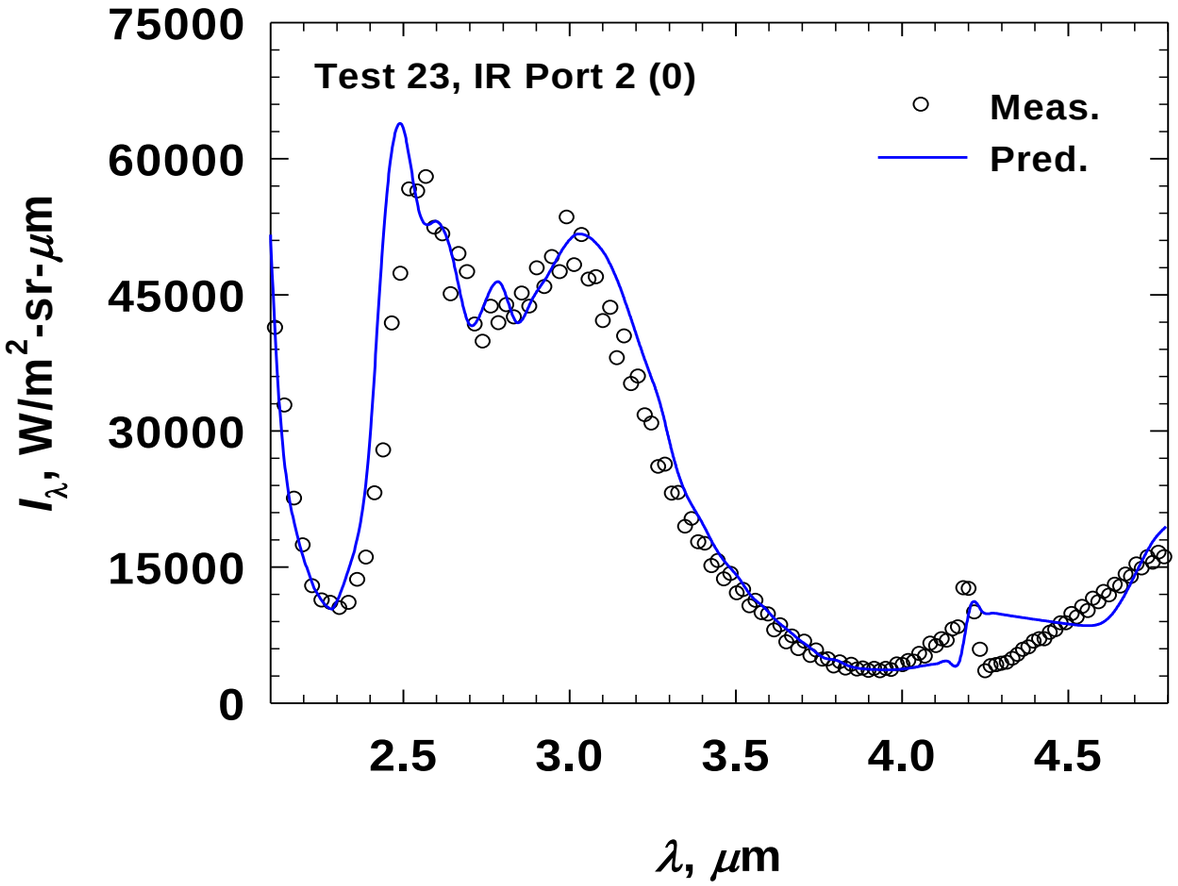
Results and Discussion

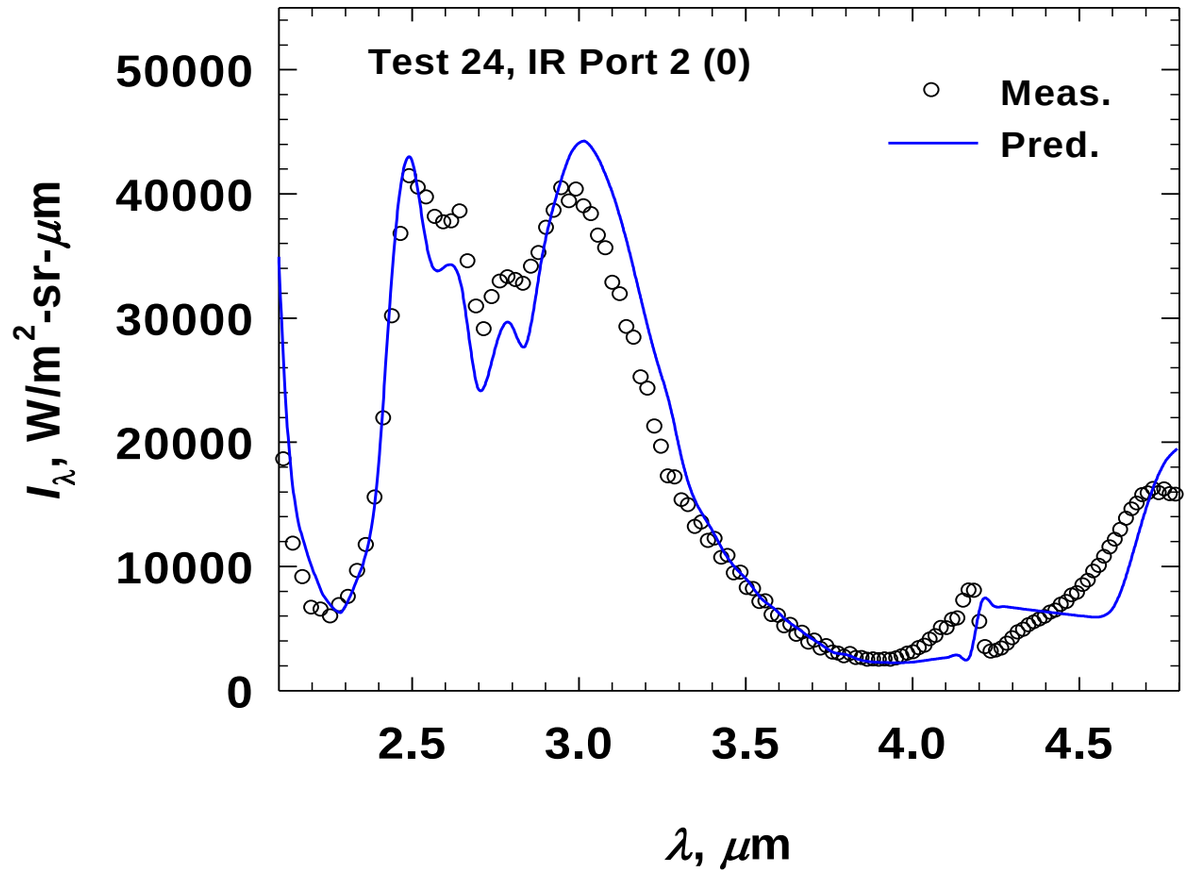


Comparison of estimated temperature profiles

- Peak temperatures of HT oxy-fuel flames are MUCH higher
- Temperatures of LT oxy-fuel air-firing flames are comparable
- Gas temperature near the wall of the HT oxy-fuel without FGR configuration is the highest

Results and Discussion

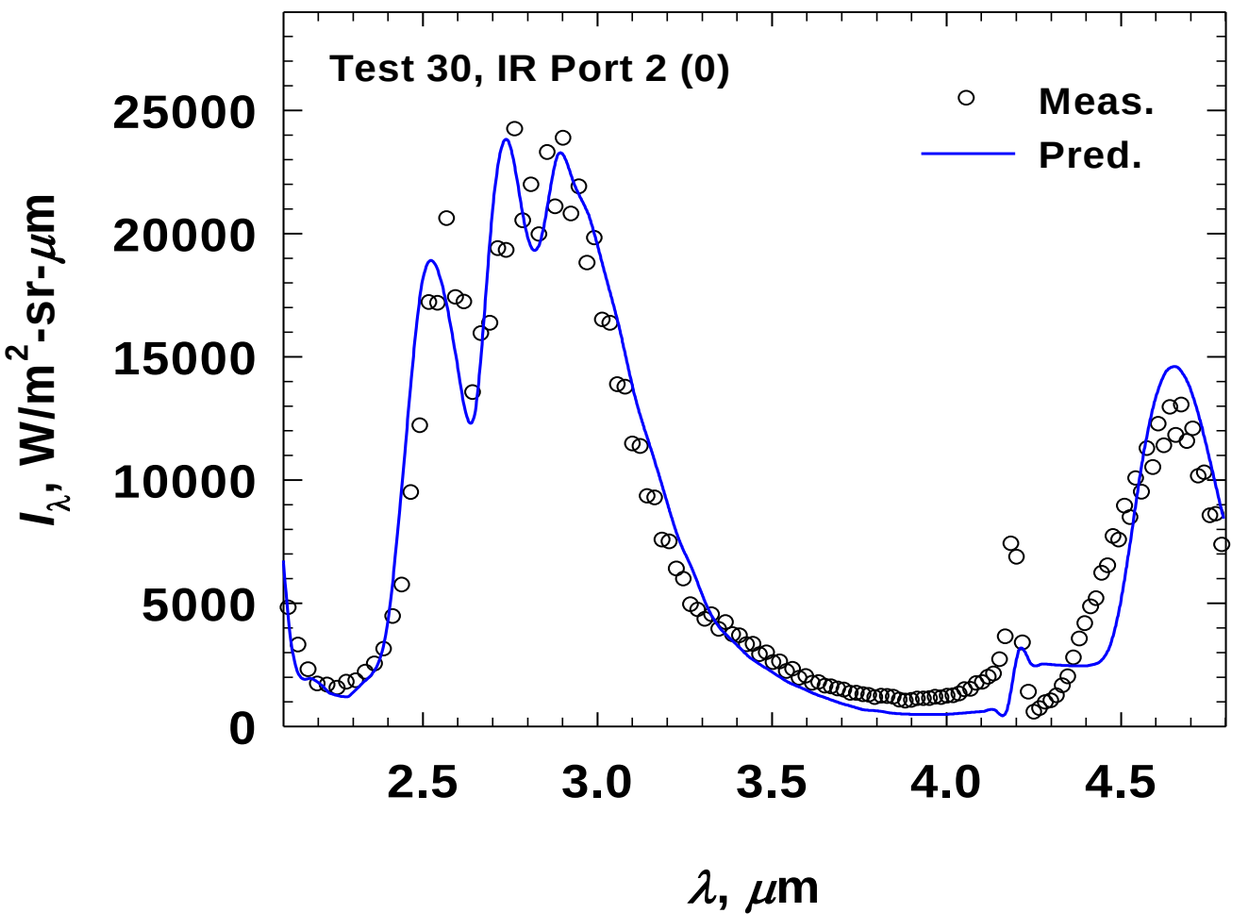


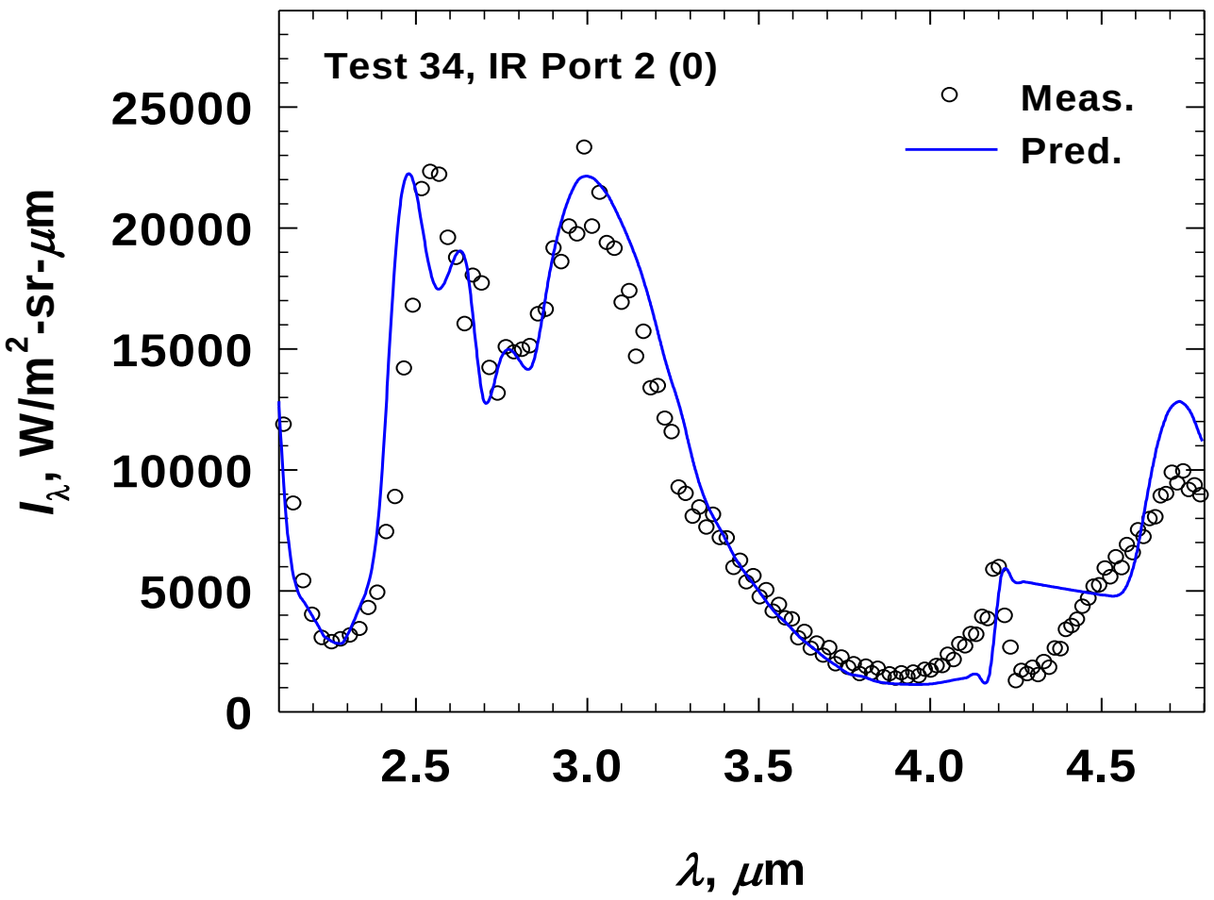


Comparisons of measured and predicted I_λ

- Test 23: HT oxy-fuel without FGR
- Test 24: HT oxy-fuel with FGR (CO_2 blanket)

Results and Discussion





Comparisons of measured and predicted I_λ

- Test 30: air firing
- Test 34: LT oxy-fuel with FGR (synthetic air)

Results and Discussion

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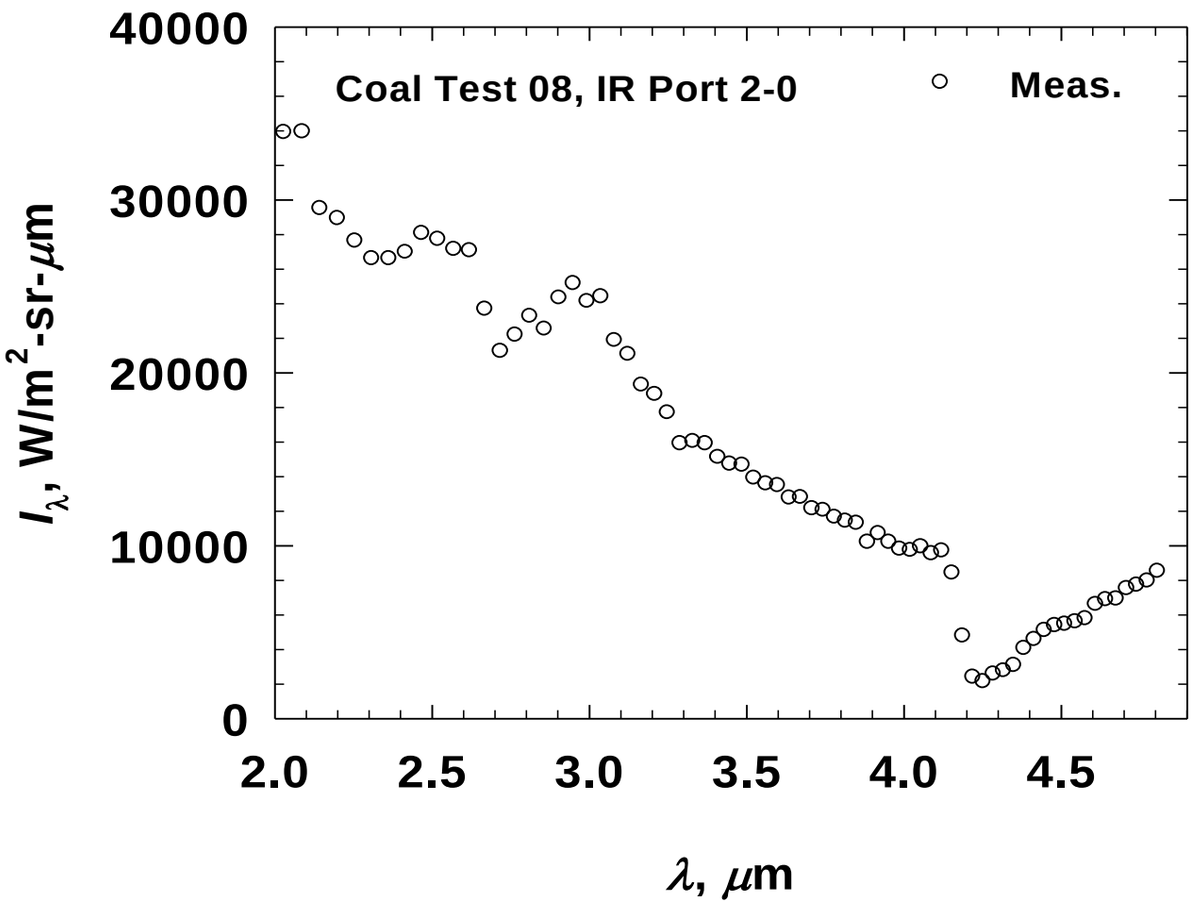
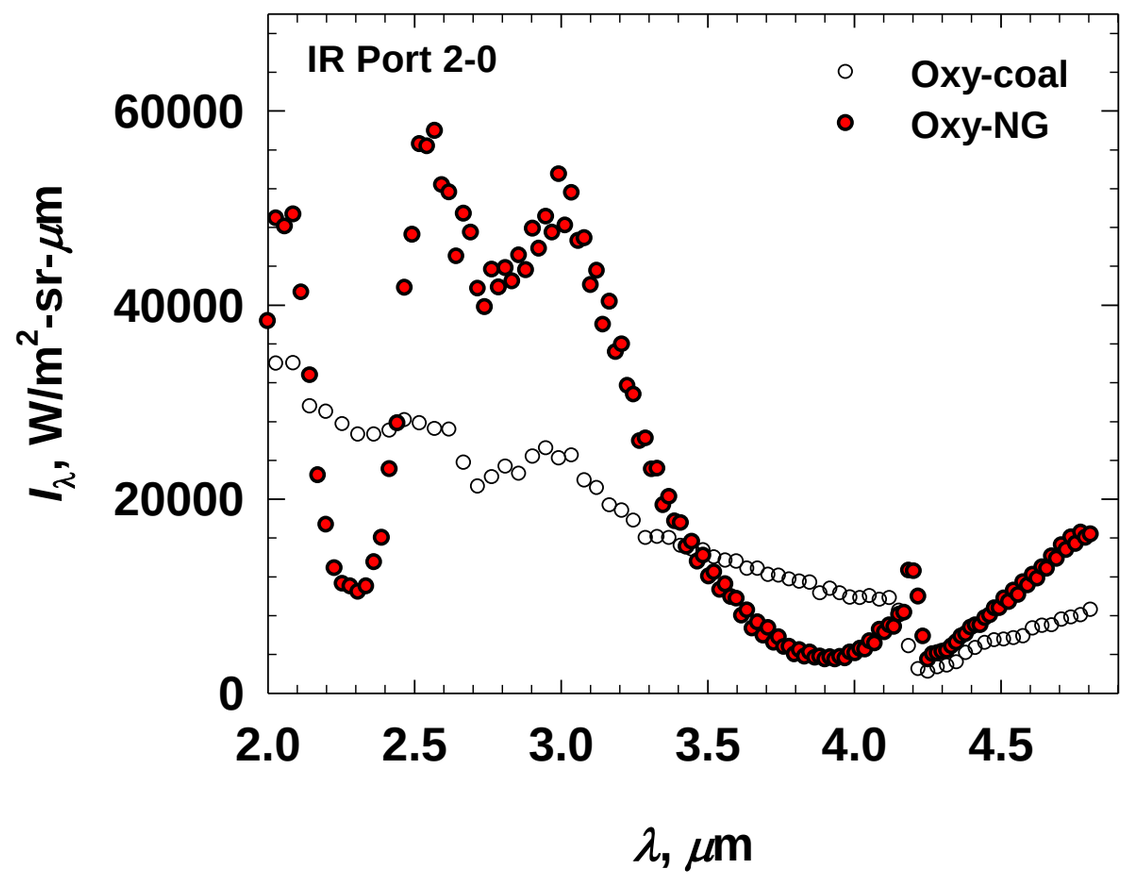
Comparison of I_λ of oxy-coal and oxy-NG flames





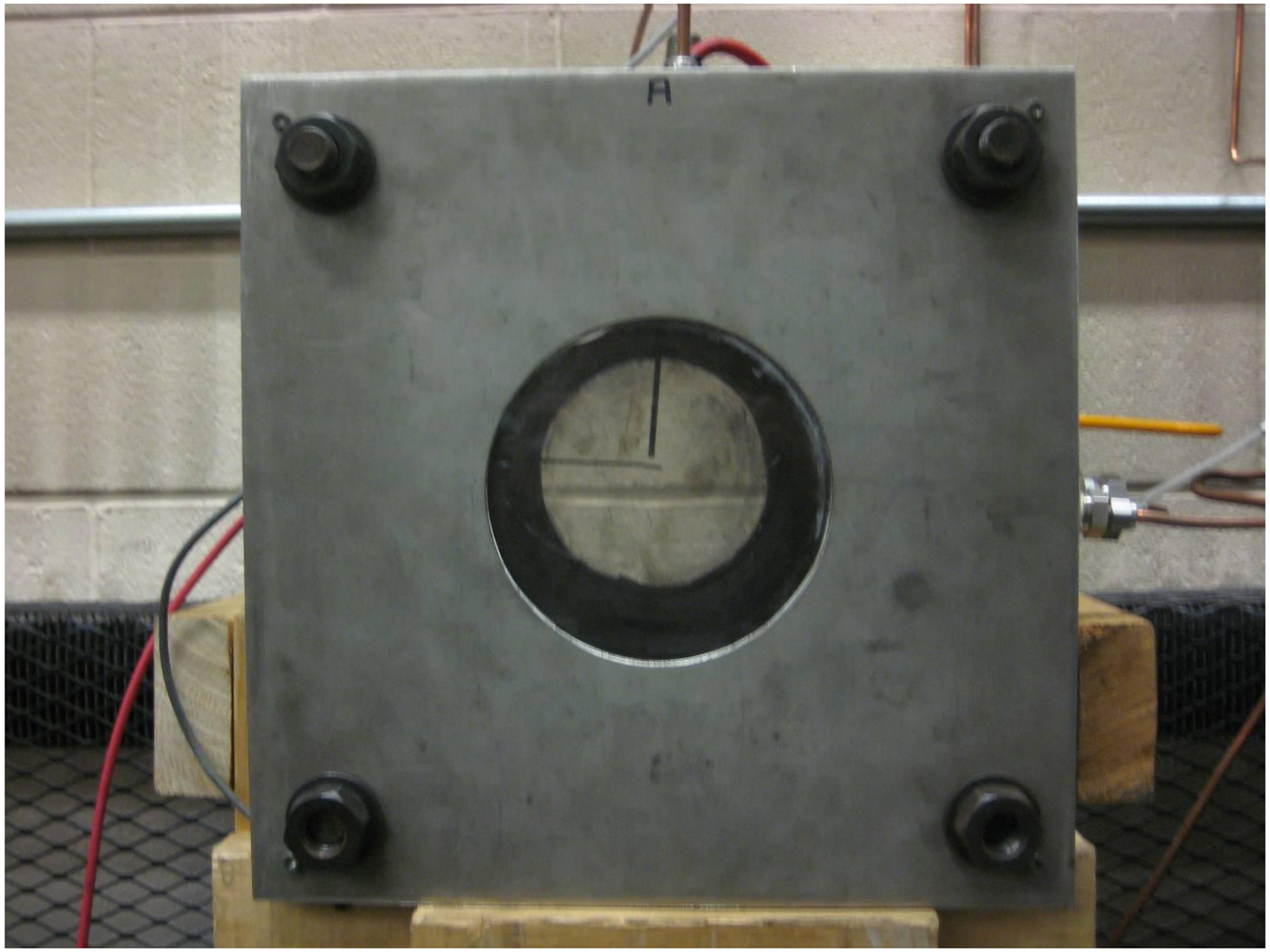
Measured I_λ of oxy-coal flame

- Continuum radiation from particles
- Much smaller dips at 2.3, 2.7 and 4.0 ⌠m
- Big dip at 4.2 ⌠m

- Same measurement location
- Slightly different heat rate
- Maybe different flame length
- Maybe different flame temperature

Combustion Studies at Purdue

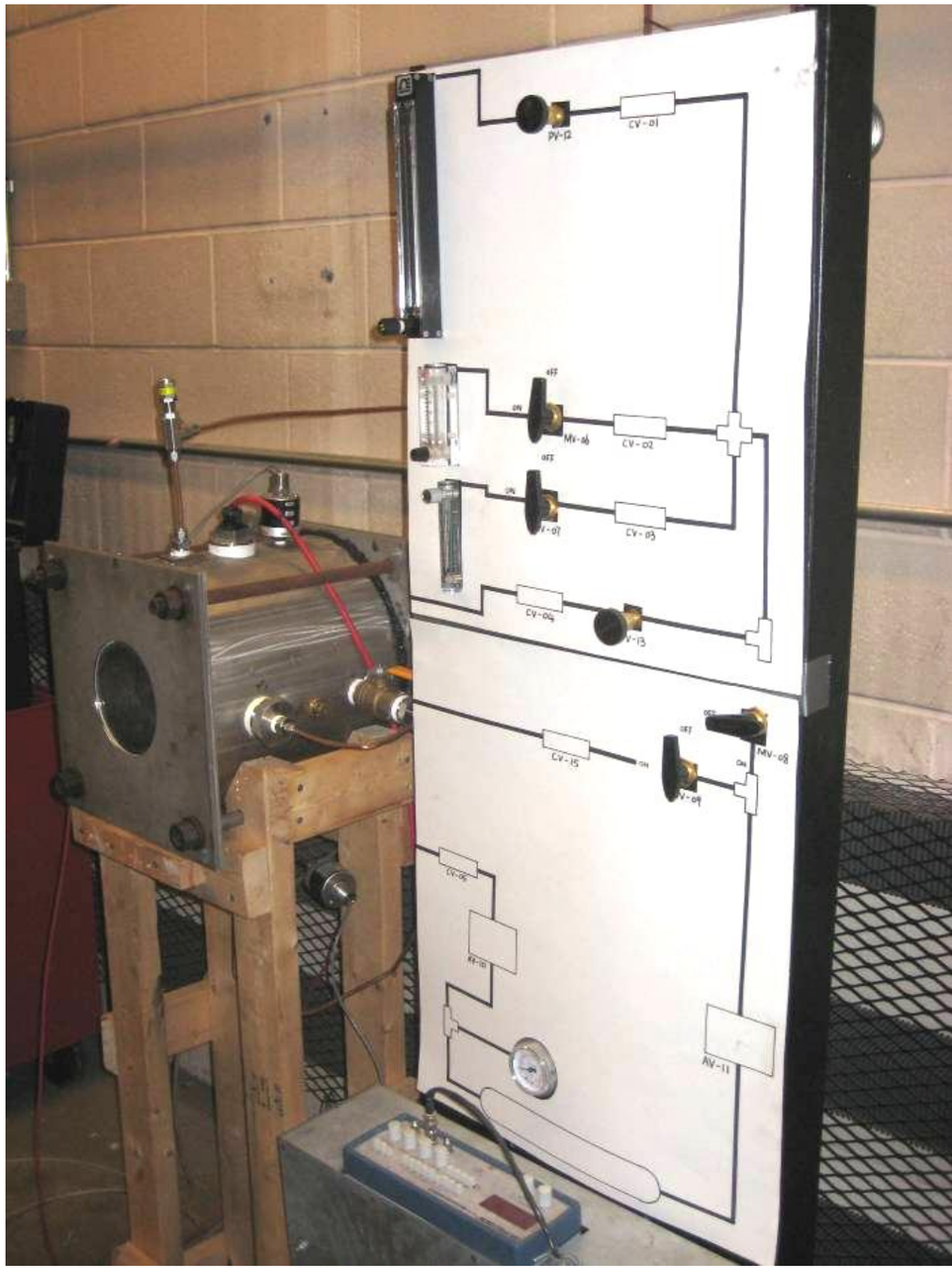
- Constant volume or pressure ignition and combustion
  - Flame and ignition characterization studies
  - Pollutant concentrations
  - RFG/O_2% optimization
  - Comparisons with Jupiter pilot reactor
  - Indiana coals considered



Can we stabilize O_2/CO_2/Coal flame with lower O_2 concentration?

Measurements:

- Flame Speed Measurements
- Radiation measurements
  - Temperature Profile of Flame using Inverse Flame Measurement Technique



While Varying:

- Initial Gasses (Oxygen, Nitrogen, Carbon Dioxide)
- Fuel/Oxidizer Ratio (Amount of Coal)
- Coal Particle Size
- Coal Type

Recent Milestones

- Repeatable combustible dust cloud combustion
- Compared with literature results
- Classification of Particle Size (Malvern Testing)
- Collected a few of coal types
- Developed Control System to run dust Cloud experiments

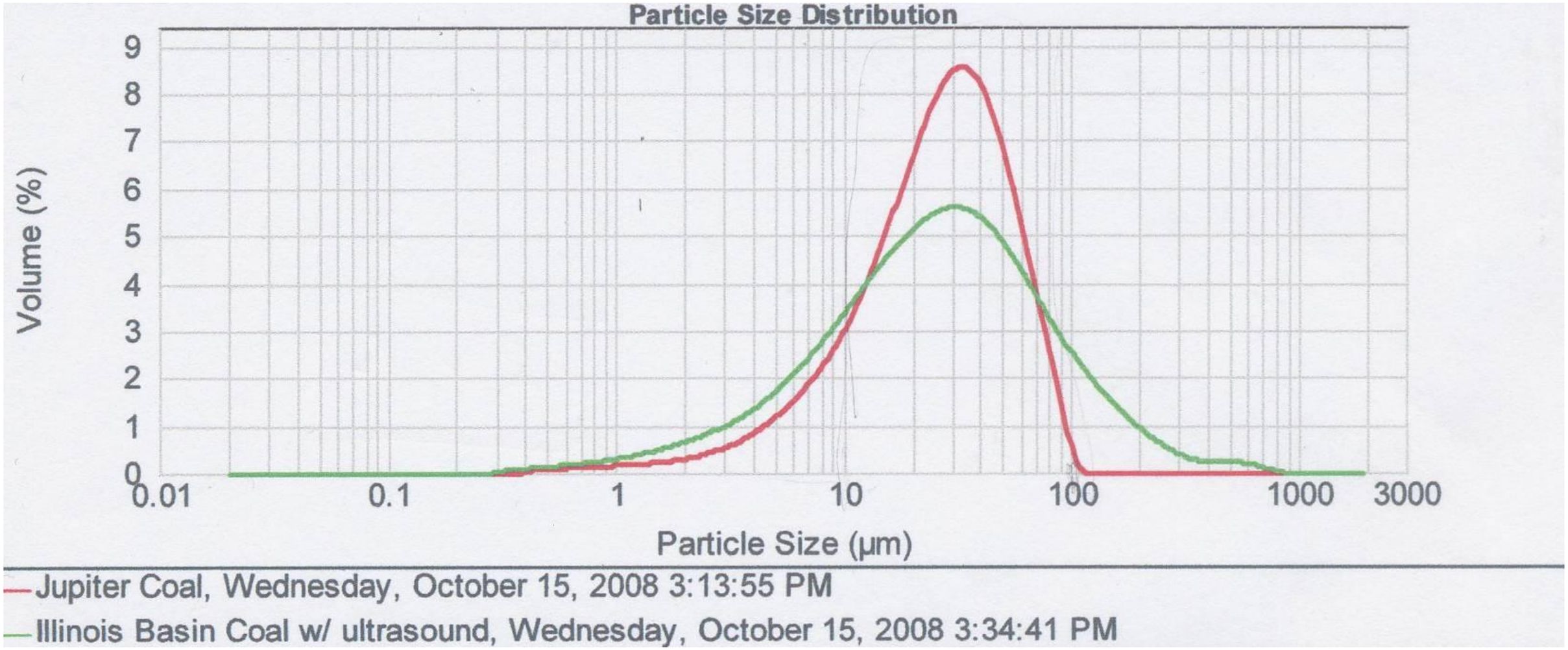
Types of Coal to be Tested

Coal Type	**Indonesian Coal**	**Illinois Basin #6**	**Indiana Coal (Billings Mine)**
Coal Classification	Bituminous (low sulfur)	Bituminous	*Bituminous (medium Volatile)
	Ultimate Analysis (%)		
Carbon	73.70%	68.30%	81.40%
Hydrogen	5.20%	5.00%	4.80%
Oxygen	18.80%	13.80%	4.60%
Nitrogen	1%	1.30%	1.60%
Sulfur	0.10%	3.50%	0.70%
Ash	1.30%	8.10%	6.90%
	Typical Proximate Analysis (%)		
Moisture	16.12%	10.10%	
Ash	1.06%	7.30%	6.90%
Volatile	42.59%	35.90%	29.20%
Fixed Carbon	40.23%	46.70%	63.90%



*Analysis of Indiana Coal Billings Mine is estimated on normal composition of coal from that area

Classification of Particle Sizing



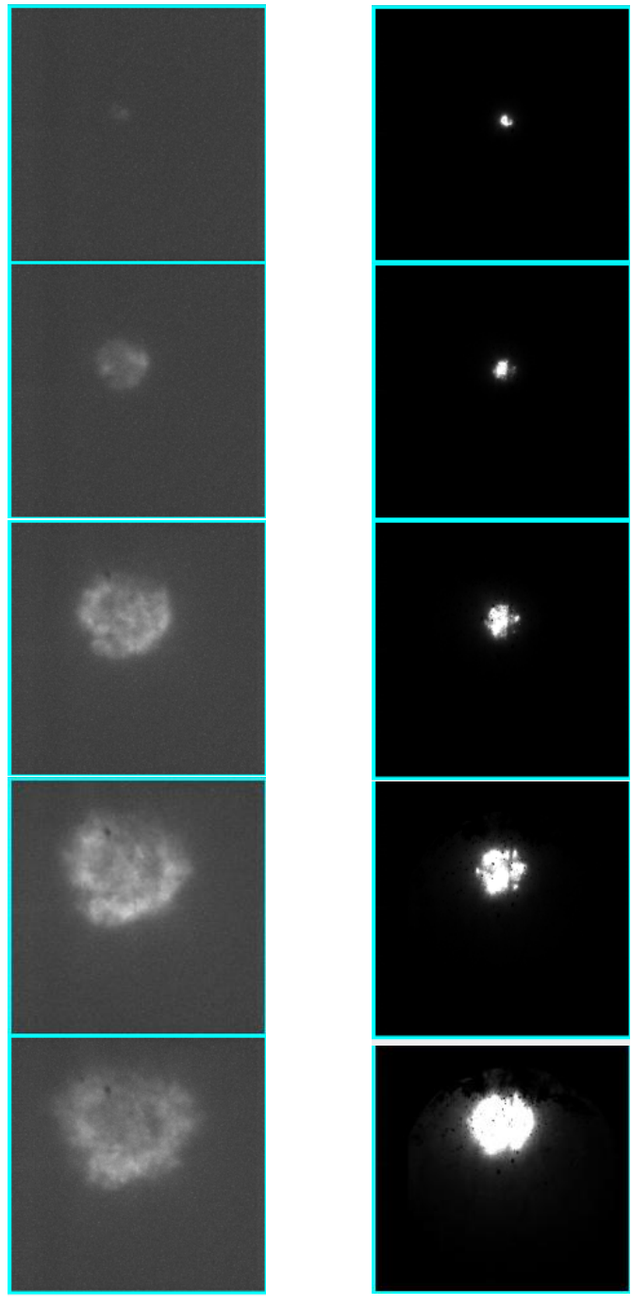
Measured Size Distribution of Coal Particle Diameter
Using Malvern Mastersizer 2000

Classification of Particle Sizing

Using Sieves we will further classify the Coal into bins of:

- >106 µm
- 106 µm - 75 µm
- 75 µm - 53 µm
- 53 µm - 25 µm
- < 25 µm

Cloud Burner Experiments



Experiment A

Indonesian coal:

50% O_2

50% CO_2

.539 kg/m^3

Experiment B

Indonesian coal:

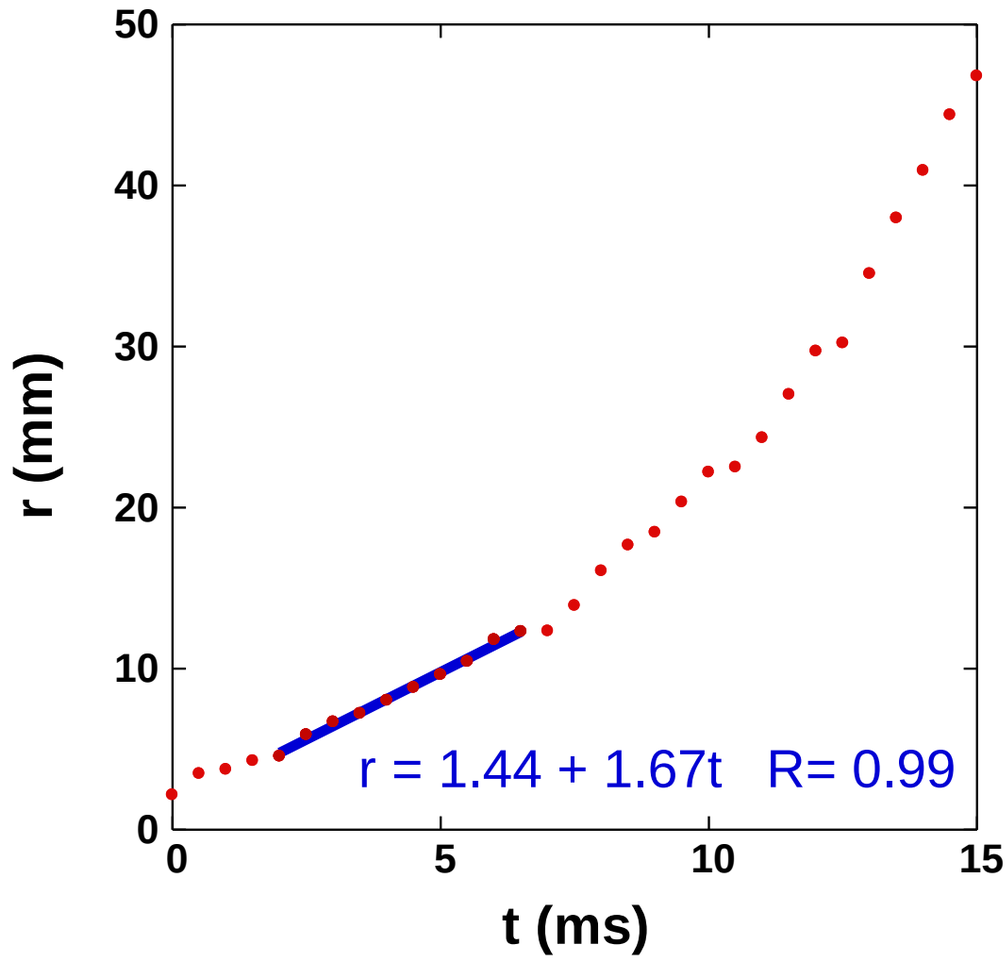
50% O_2

50% CO_2

.539 kg/m^3

Particle size < 25μm

Cloud Burner Experiments



50% Oxygen and 50% CO_2, 0.539 kg/m^3
amounts of a similar Bituminous coal

Suda reports ~1.3 m/s

Purdue Study ~1.7 m/s

Size, O_2 conc. Differences, etc.

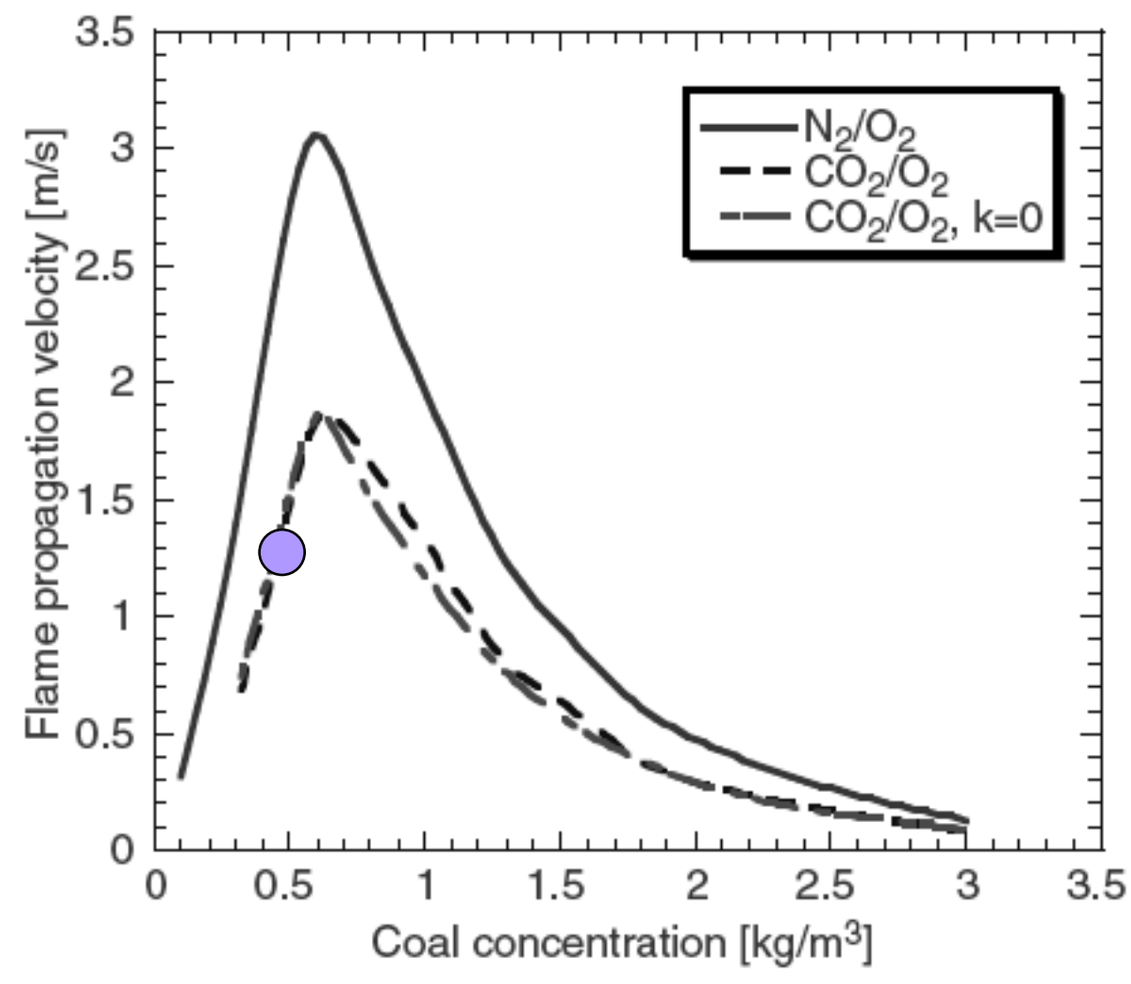
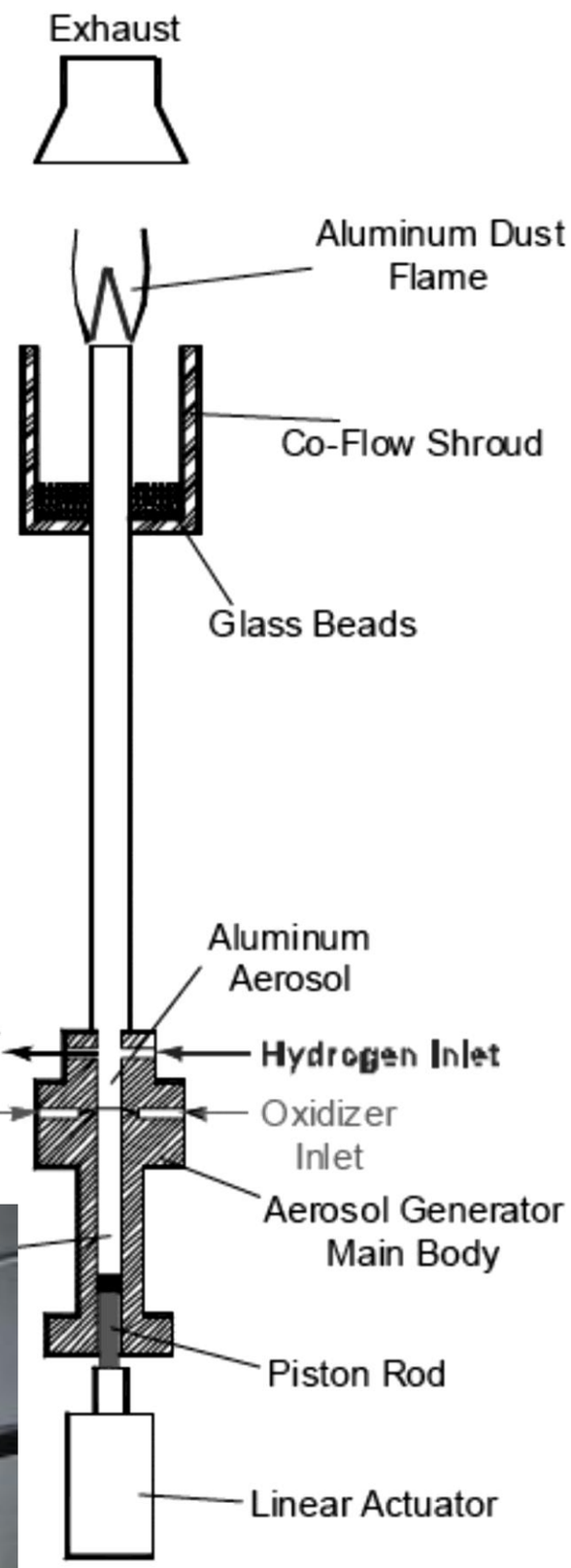


Fig. 10. Effect of CO_2 on flame propagation velocity Coal A, 50 μm.

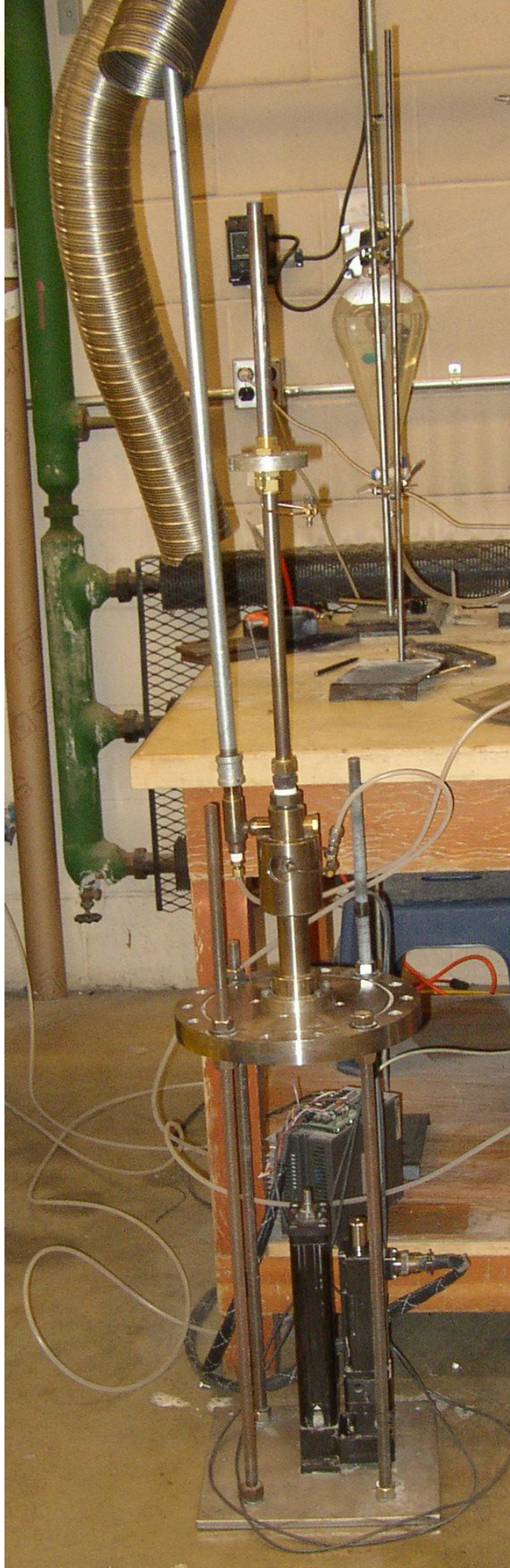
Bunsen Particle Burner (PSU)

Natural Gas
Pilot Flame

Also trying hot-wire Stabilization



Using a low-flow natural
gas pilot flame we can
Stabilize the coal/oxygen
Bunsen burner



Summary of Progress

- Radiation measurements in pilot burner
- New particle cloud combustor built
  - Initial laboratory measurements made
- Obtained pulverized coal for studies and characterized
- Bunsen particle burner
  - Being adapting to coal combustion
  - Complements particle cloud experiment

Future Work

- Conduct parametric studies of laboratory scale oxy-coal flames
  - Various oxy-coal configurations
  - Spectral radiation intensity measurements from NIR to IR
  - Inverse estimates of temperature and species concentrations
  - Compare to pilot scale

Acknowledgements

This work was funded by Jupiter Oxygen and CCTR (Indiana)

The radiation data were acquired by Jupiter Engineers, Steven Neid, Cassidy Jax, and Brian Patrick

Appendix: Temperature Estimate

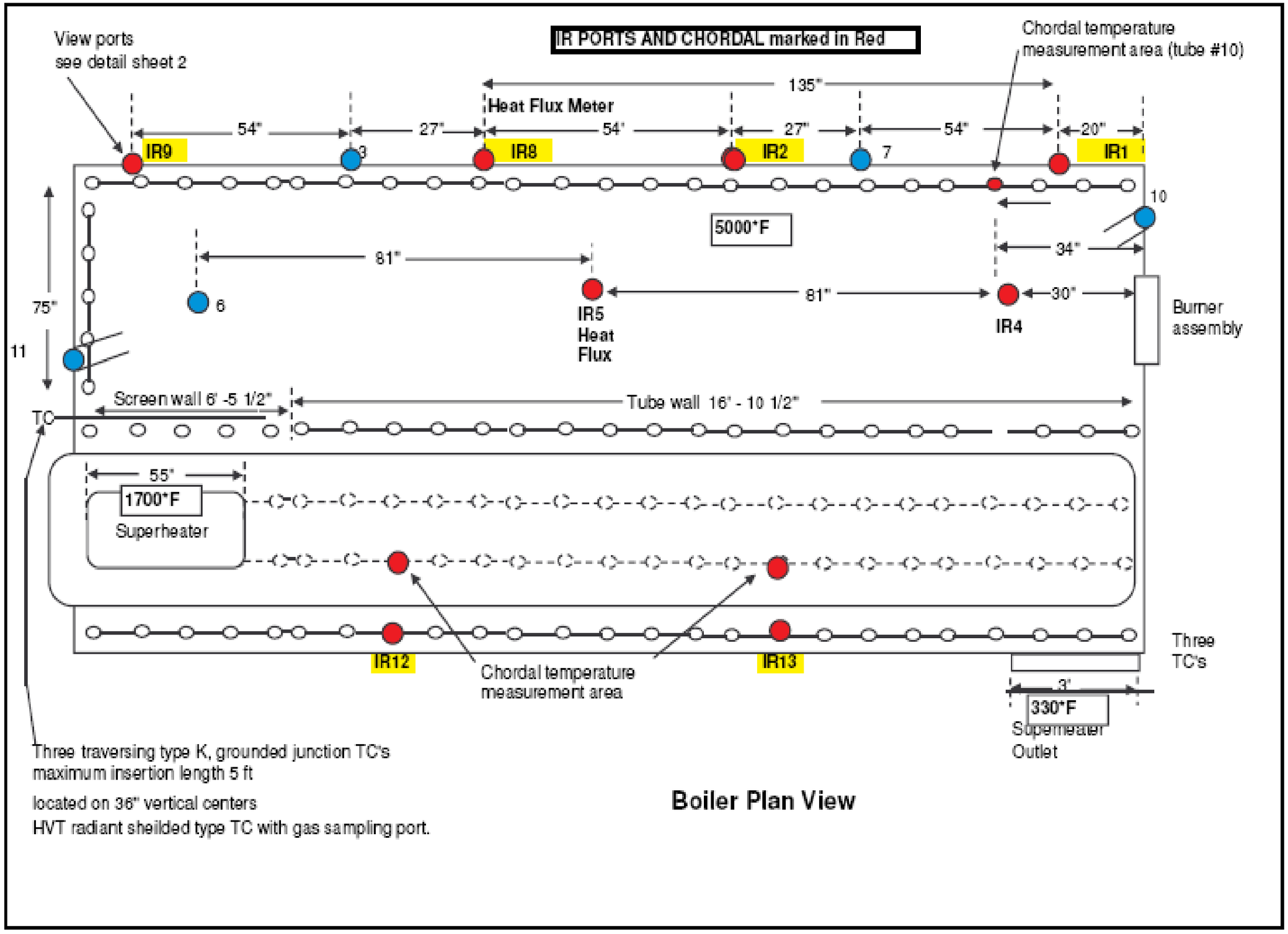
We estimated the temperature profile using the following major assumptions,

1. Turbulent effects are not considered as a first approximation
2. Negligible radiation from the wall
3. Constant species (CO_2, H_2O, O_2, etc.) concentrations. The species concentrations were obtained by thermodynamics calculations using HYSYS (Jupiter's calculation)
4. The temperature profile was described as the following,

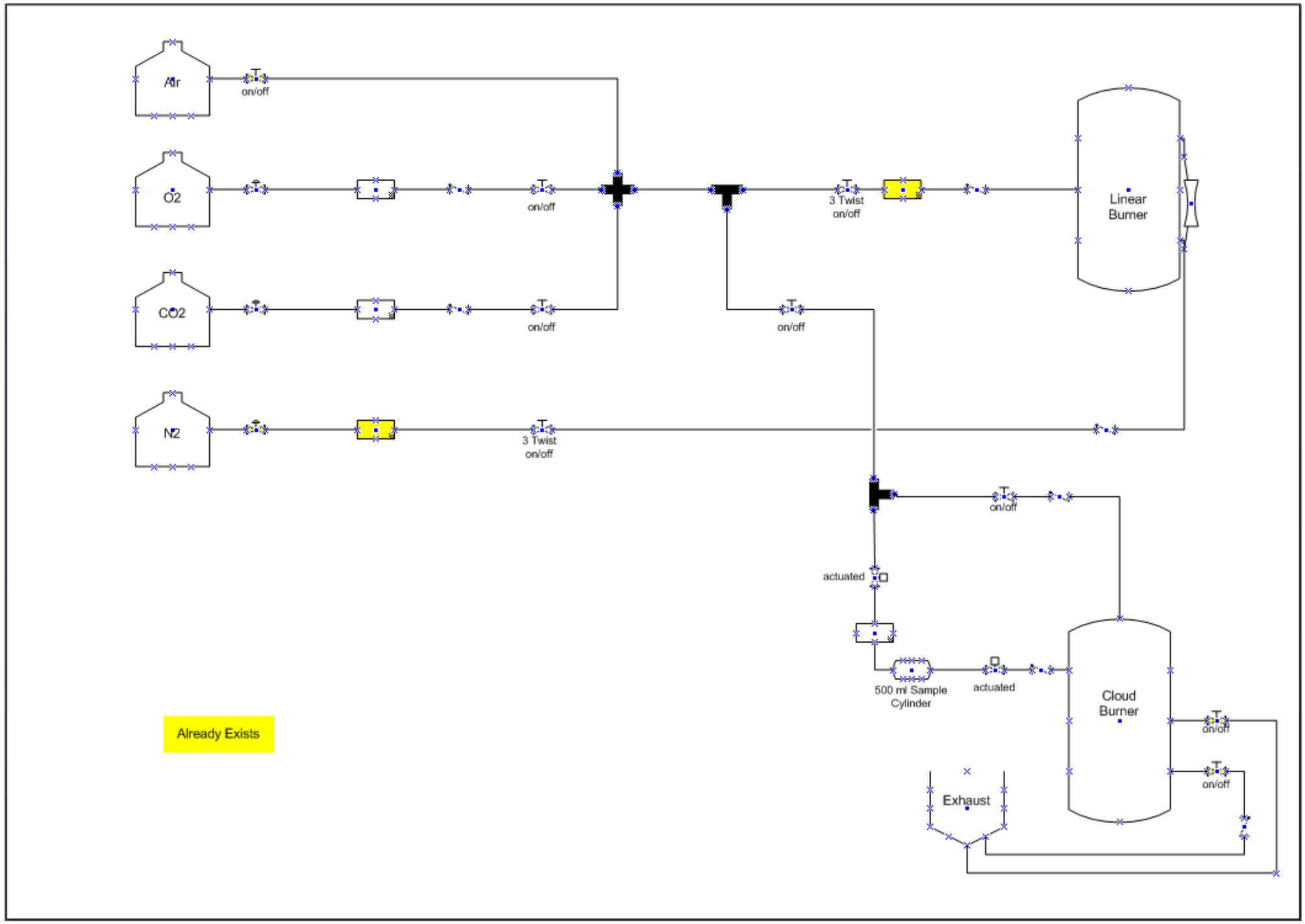
$$T(r) = T_p \exp\left[-\left(\frac{r - r_p}{c}\right)^2\right] + T_b$$

where the normalized position, r, is zero at the center and unity at the water wall boundary. The four parameters (T_b, T_p, c, and r_p) are related to the gas temperature at the boundary (T_b), the normalized location of the flame front (r_p), the flame front temperature ($T_p + T_b$), and the gas temperature at the flame center. These parameters were first guessed and then determined when the calculated I_λ based upon these parameters were optimized to yield the best fit to the measured I_λ at four (at least) specifically chosen wavelengths.

Test Arrangement



Piping Diagram



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