Sub-micron Ash Aerosol Formation in Oxycoal Combustion at Atmospheric and Elevated Pressures

36th Annual International Pittsburgh Coal Conference

Westin Convention Center Hotel

September 3-6, 2019

For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

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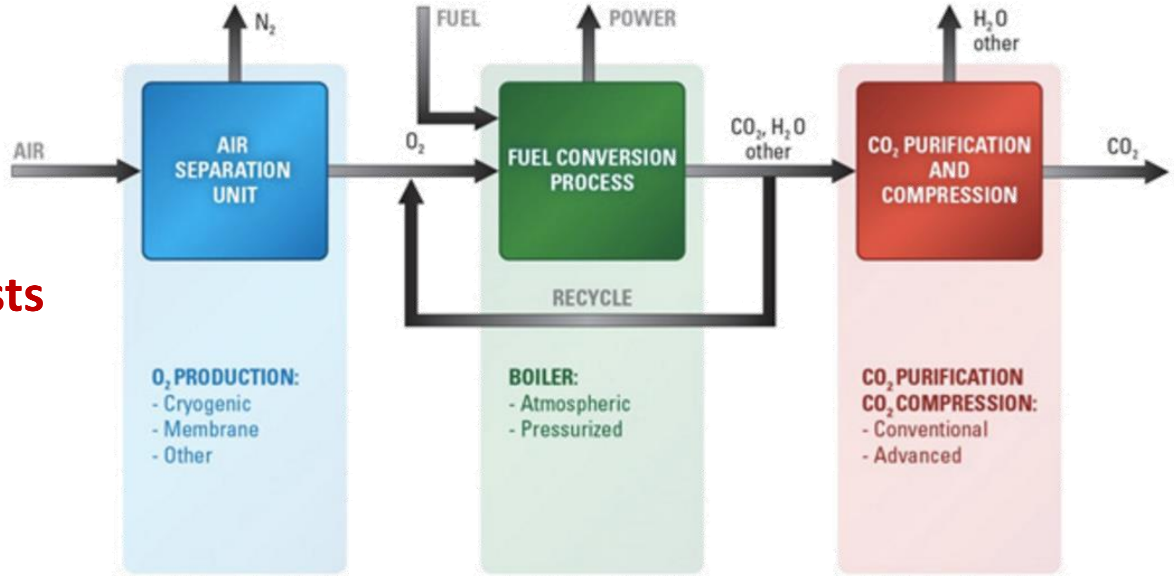
Motivation for Current Work

- Continued utilization of coal power in a carbon constrained environment will require Carbon Capture Utilization and Sequestration (CCUS)
- Utilization of conventional coal conversion technologies in combination with existing CCUS technologies is currently far from economically feasible
- Advanced coal conversion systems involving high temperatures and pressures can be effectively integrated with state-of-the-art CCUS and offer a more promising approach

↑ **Efficiency**

↓ **Emissions**

↓ **Capital and operating costs**



http://www.netl.doe.gov/research/coal/energy-systems/advanced-combustion/oxy-combustion

REI-Led Oxy-Coal Combustion Programs

Enabling Technologies for Advanced Oxy-Coal Combustion Systems

Characterizing Impacts of High Temperature and Pressures in Oxy-Coal Combustion Systems (HTHP)

September, 2015 – August 2018

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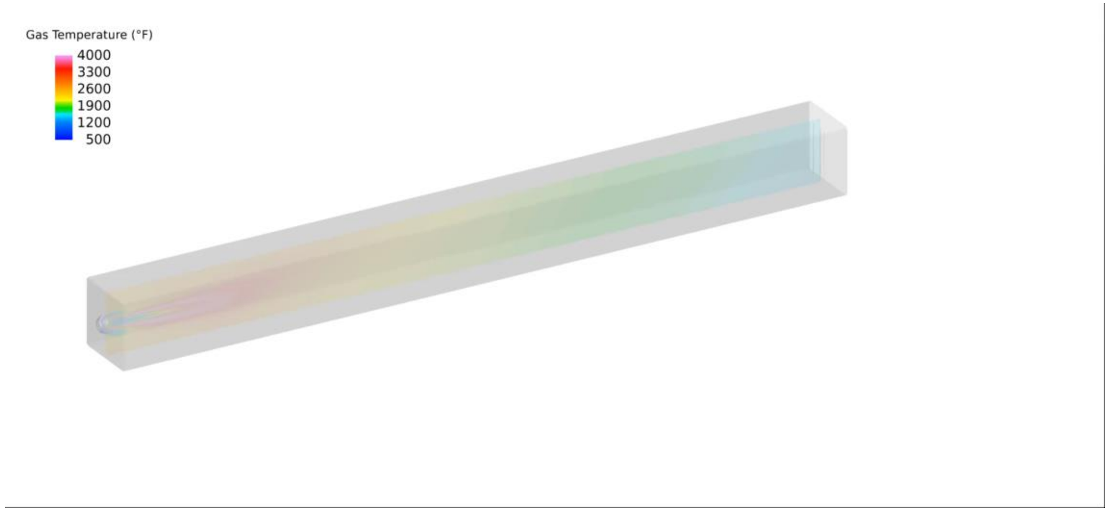
PRAXAIR

Jupiter Oxygen



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Characterizing Impacts of Dry Coal Feeding in High Pressure Oxy-Coal Combustion Systems (DFHP)
October, 2016 – September 2020

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Ash Aerosol Research Objectives

- Investigate sub-micron ash aerosol formation under high-temperature and high-pressure combustion conditions
- Develop ash aerosol sampling techniques for high temperature oxy-coal combustion at atmospheric pressure and pressurized oxy-coal combustion
- Determine the effect of temperature and pressure on ash aerosol elemental partitioning
- Describe the impacts of temperature and pressure on ash particle size distributions for particles smaller than 1 micron
- Develop numerical approaches suitable for inclusion in CFD-based analyses for predicting ash aerosol behavior in 2^{nd} generation oxy-coal combustion systems

Oxy-Fuel Combustor (OFC)

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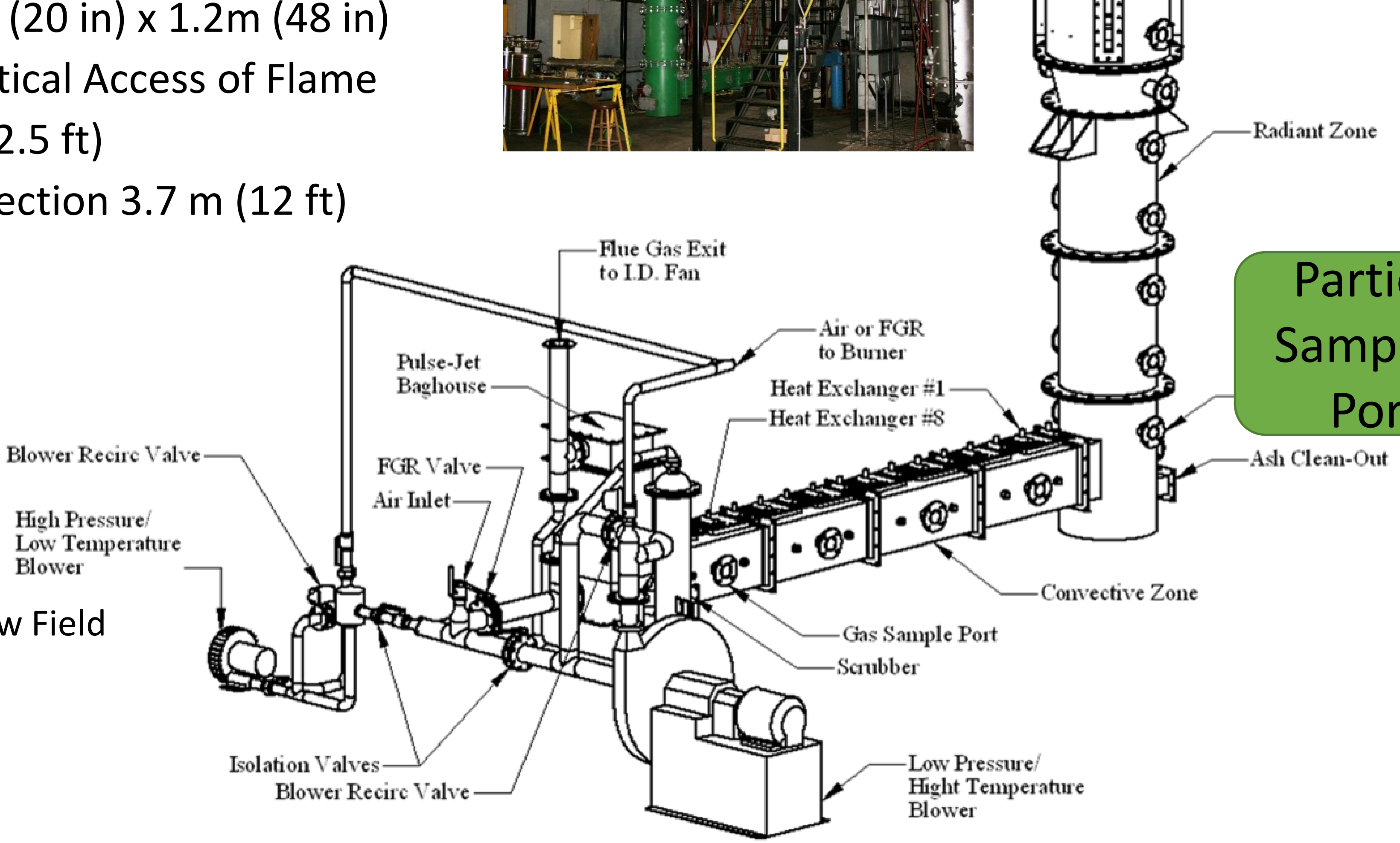
Specifications

- 100 kW (0.25 MMBtu/hr) Firing Rate
- Main Burner Zone 0.5m (20 in) x 1.2m (48 in)
- Quartz Windows for Optical Access of Flame
- Vertical Height 3.8 m (12.5 ft)
- Horizontal Convective Section 3.7 m (12 ft)

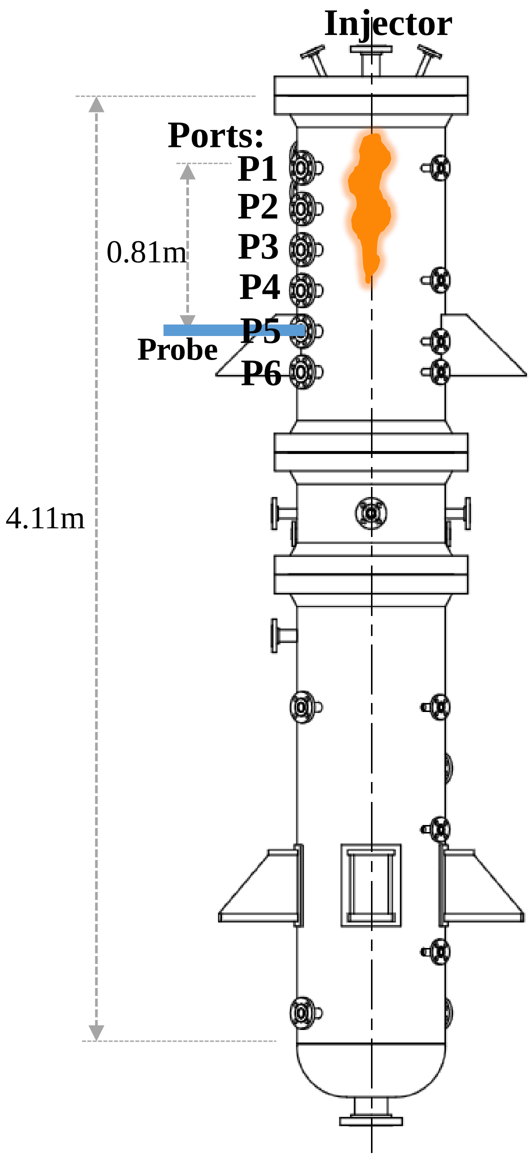
Research

- Ash Formation
    - Aerosols
    - Deposition
    - Trace Elements
- Sorbent Development
- Optical Diagnostics
    - Flame, Radiation & Flow Field



Particle Sampling Port

300 kW Entrained Flow Pressurized Reactor (EFPR)



- Converted from an entrained flow gasifier
- 300 kW (rated) pilot scale
- Coal-water slurry feeding with pure O_2
- Down-fired, self-sustained and no external heating
- Operation pressure up to 30 bar

Combustion Conditions

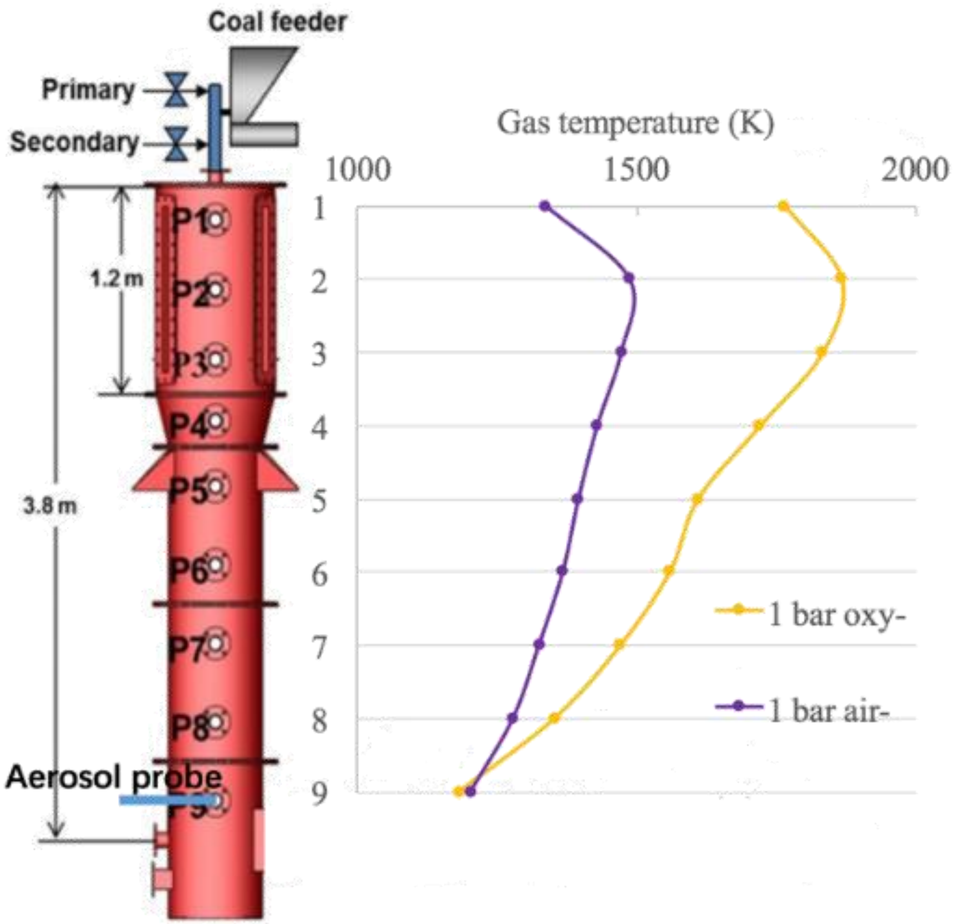
Combustion conditions

Combustor	EFPR (pressurized)		OFC (atmospheric pressure)	
Coal	Sufco		Sufco	
Feeding	slurry	slurry	dry powder	
Coal feeding rate (kg/hr)	13.22	38.60	6.80	
Firing rate (kW)	100	293	52	
Oxidation condition	oxy-combustion	oxy-combustion	oxy-combustion (OXY70)	air-combution (AIR)
Pressure (bar)	8	15	1	1
Peak temperature (K)	1698	1910	1866	1489
Flue gas at standard state (standard_m^3/hr)	78.82	209.88	18.09	55.82

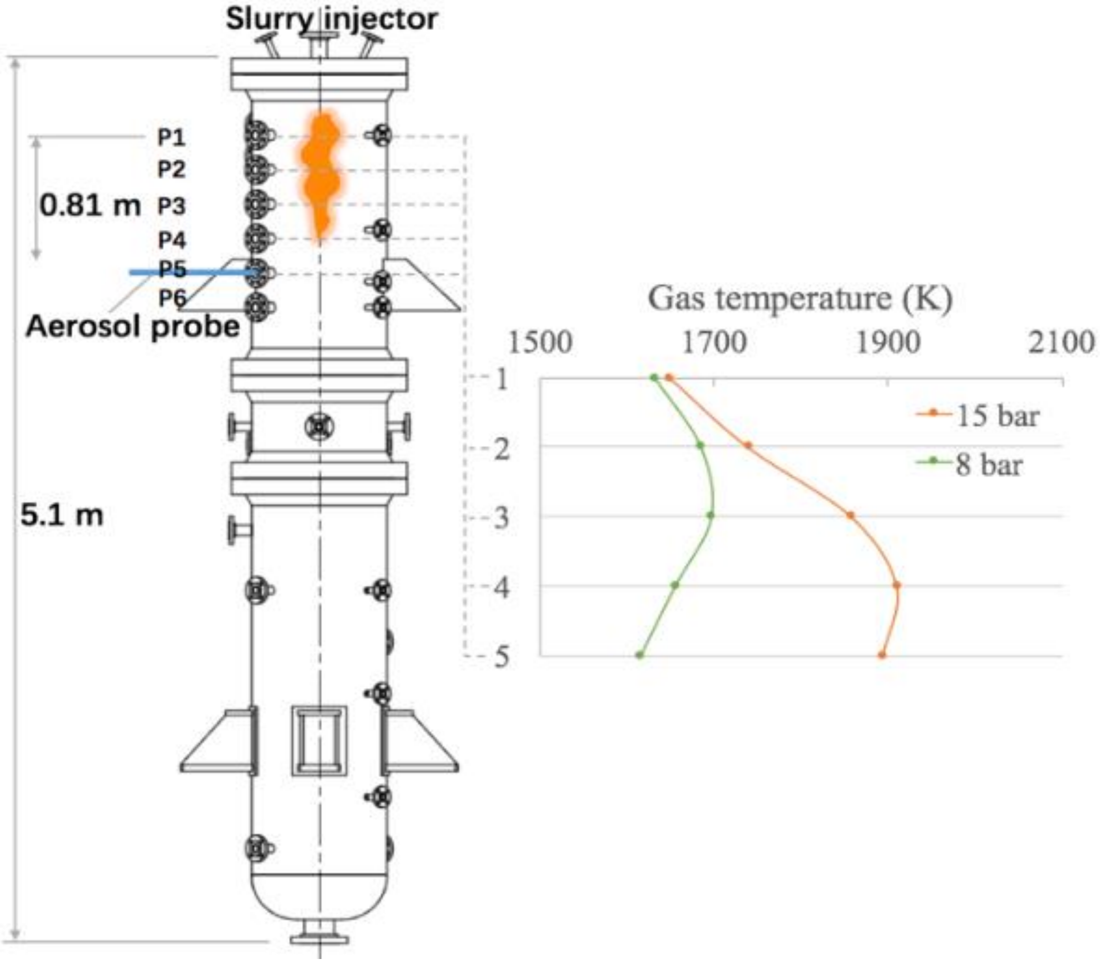
Comparison of OFC and EFPR

Gas Temperature Profiles

OFC



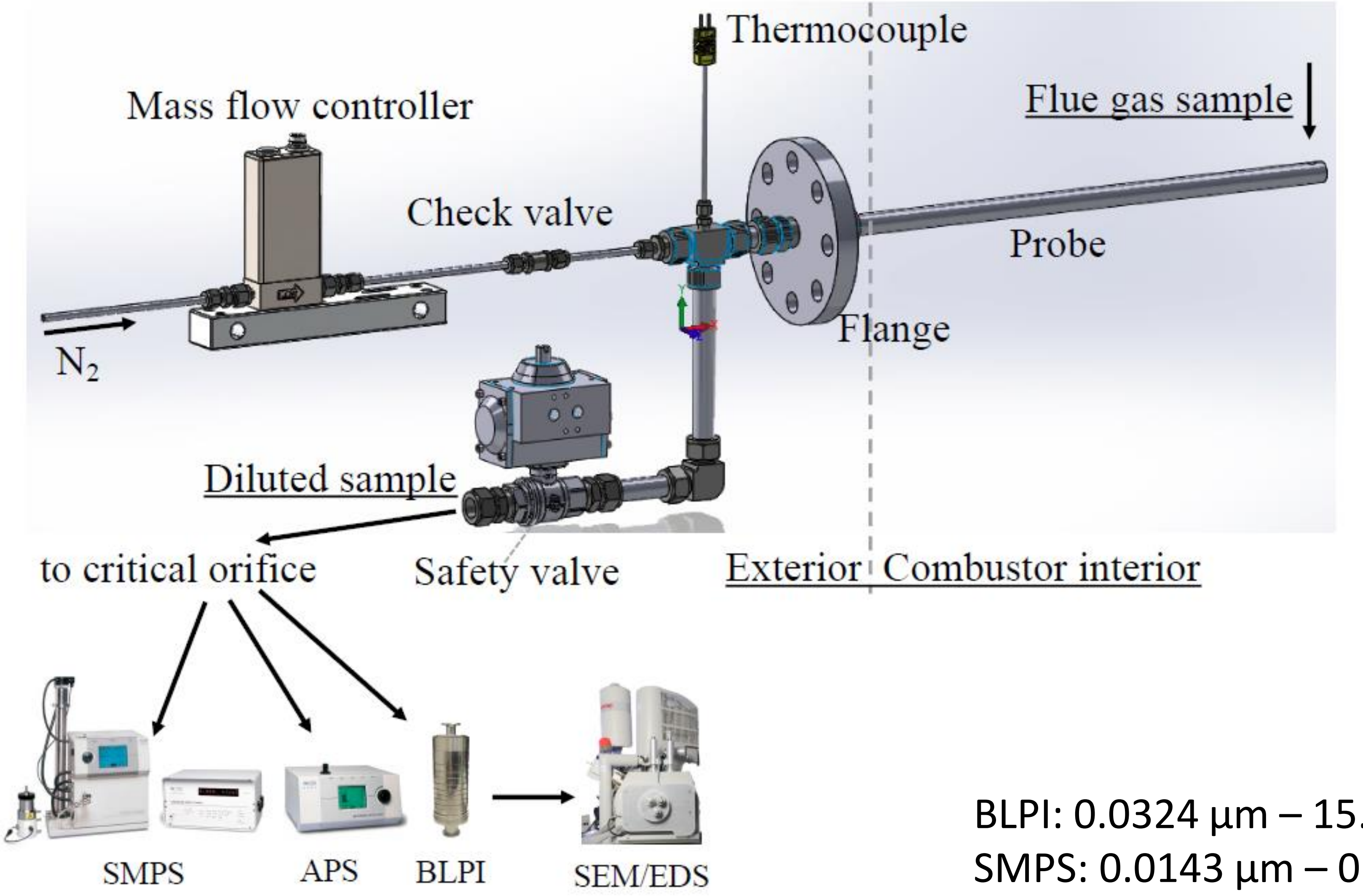
EFPR



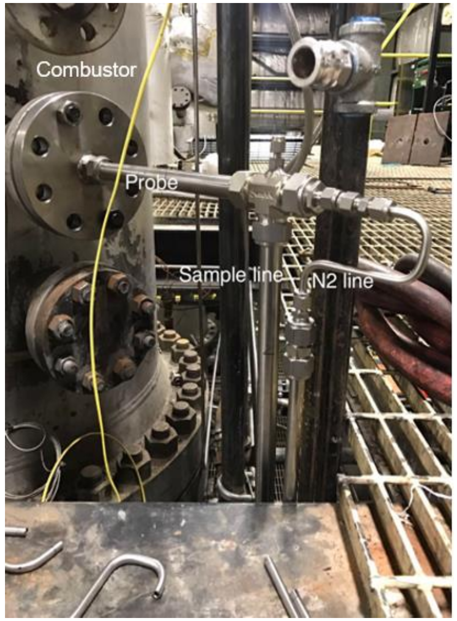
Aerosol Sampling Requirements

- Safely sample at high pressure conditions
- Preserve the integrity of the EFPR combustor
- Protect the working environment of the probe (slagging)
- Gather representative sample streams with low loss rate
- Maintain a proper temperature distribution in sampling line
  - Water condensation
  - Material working temperature

High Pressure Aerosol Sampling System



System Schematic

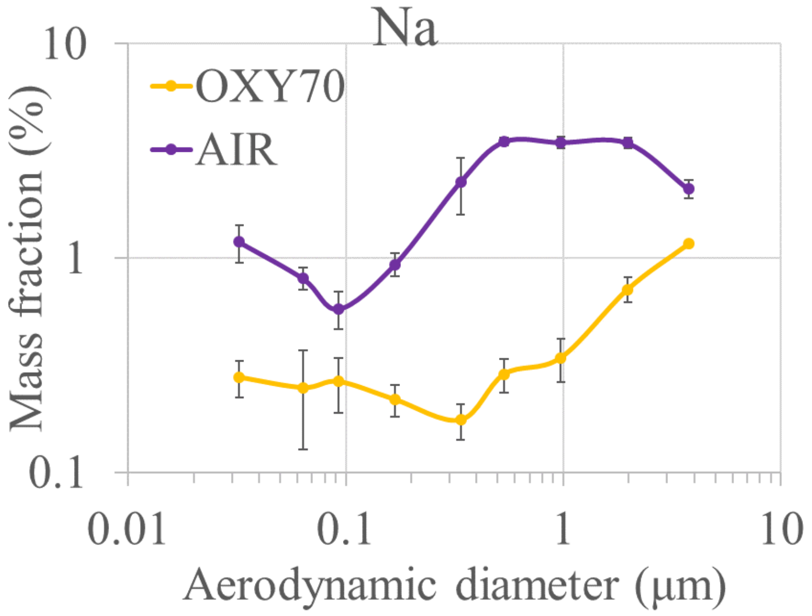


BLPI: 0.0324 μm – 15.7 μm
SMPS: 0.0143 μm – 0.6732 μm
APS: 0.532 μm – 20 μm

Size-Segregated Compositions

Impact of Temperature

Alkali at 1 bar
Oxy-coal Combustion vs. Air



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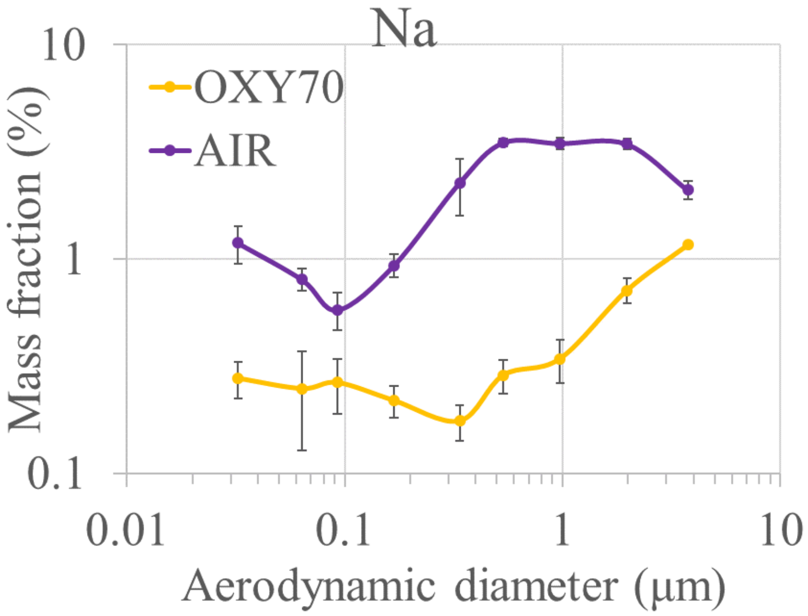
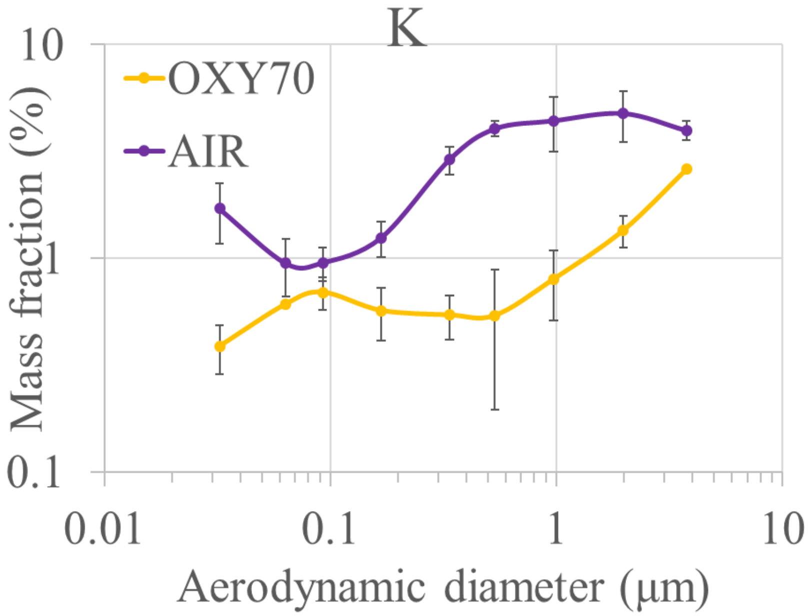
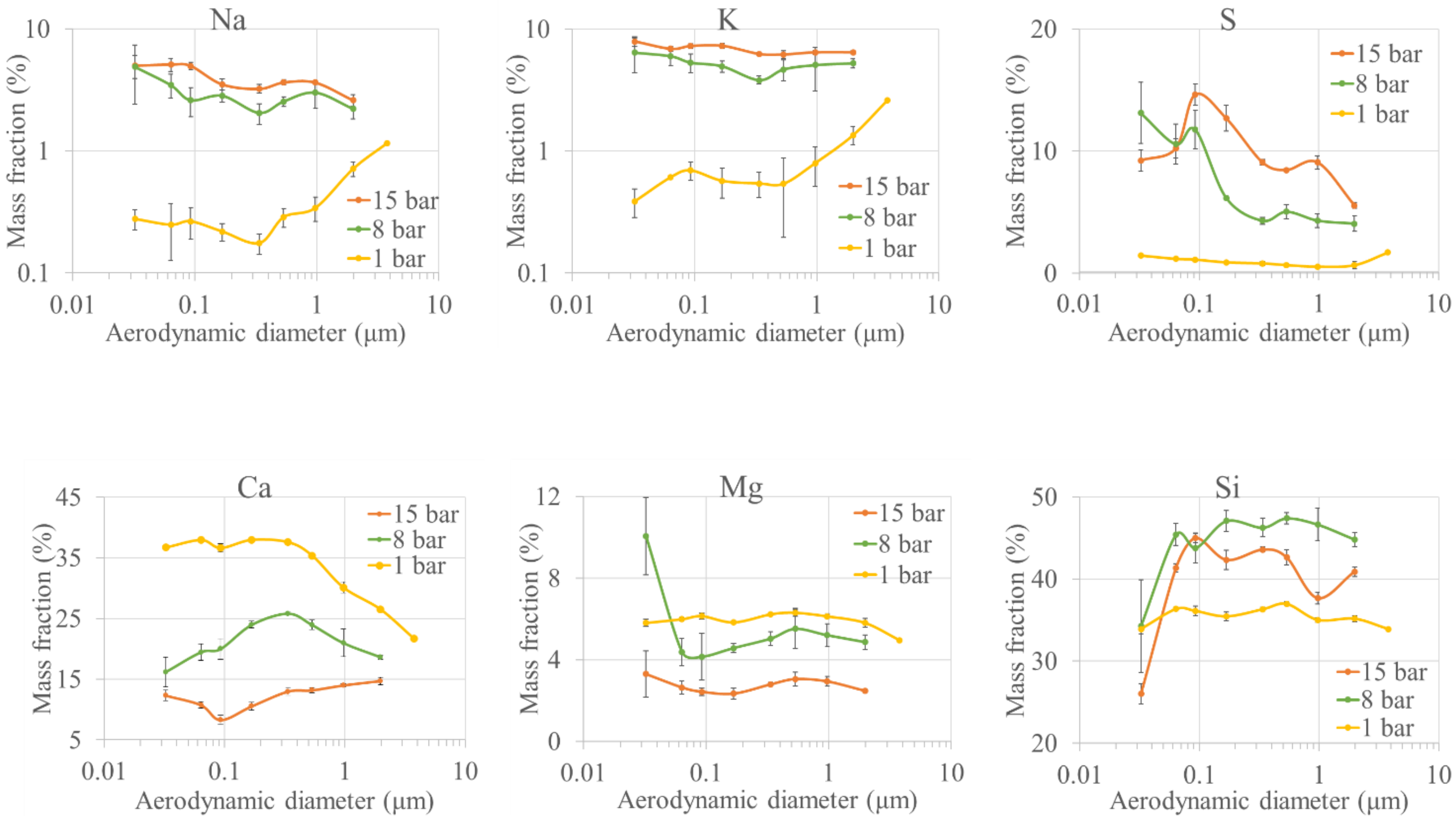




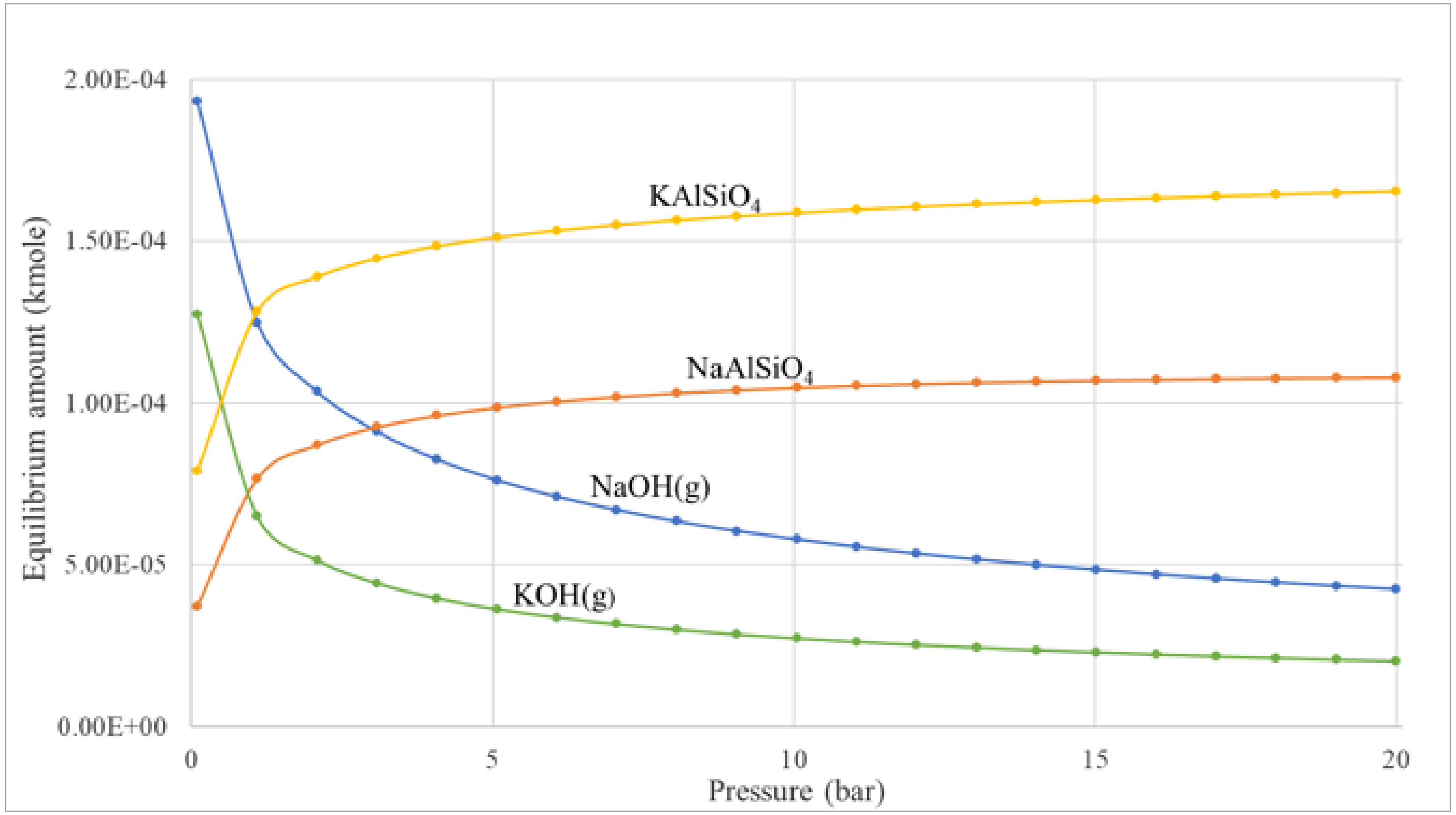
Size-Segregated Compositions

Impact of Pressure



Impact of Pressure

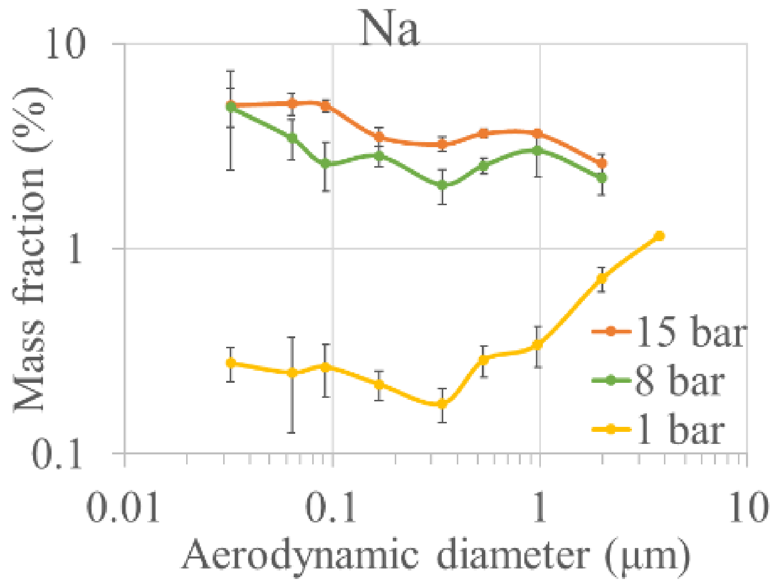
Equilibrium Calculations

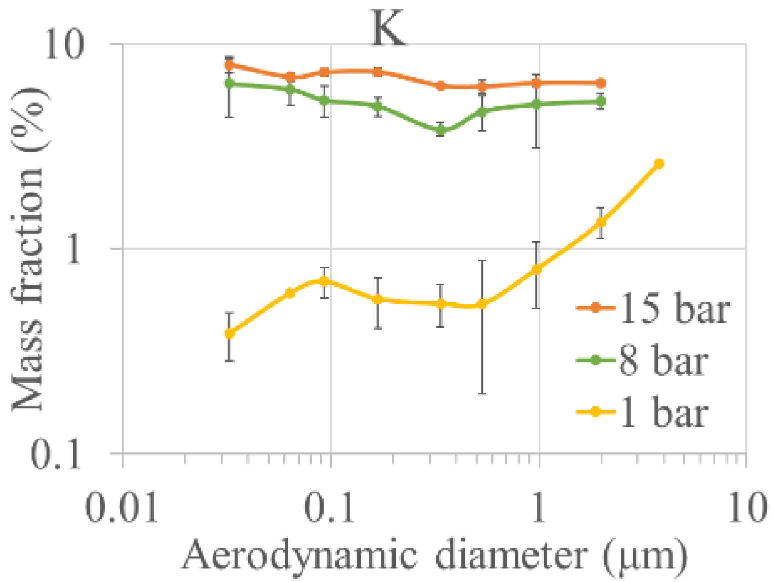


Size-Segregated Compositions

Impact of Pressure (Continued)

Alkali at 1 bar, 8 bar, and 15 bar
Oxy-coal Combustion Atmospheric vs. Pressurized





Size-Segregated Compositions

Impact of Pressure

Alkali at 1 bar, 8 bar, and 15 bar

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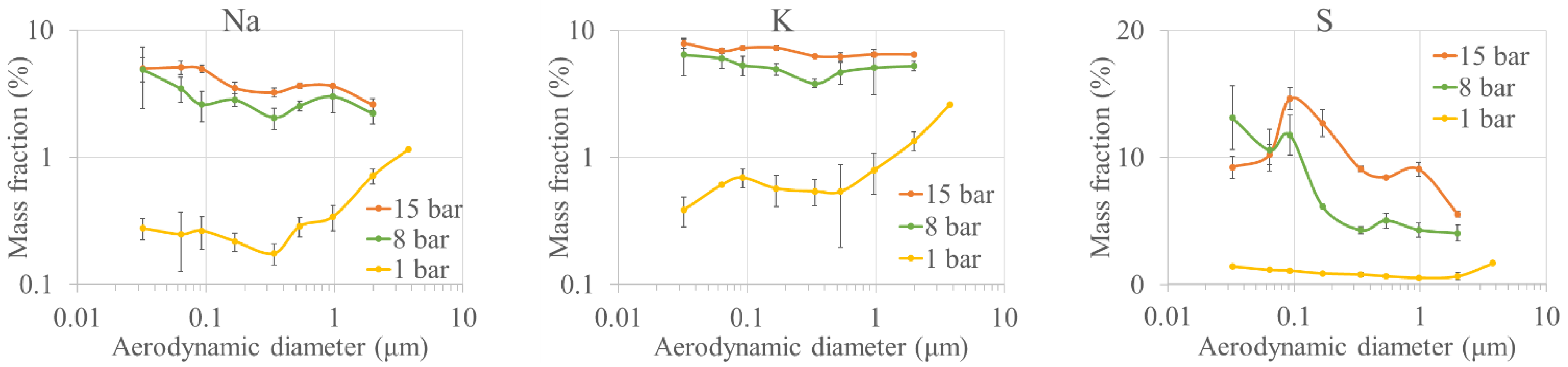
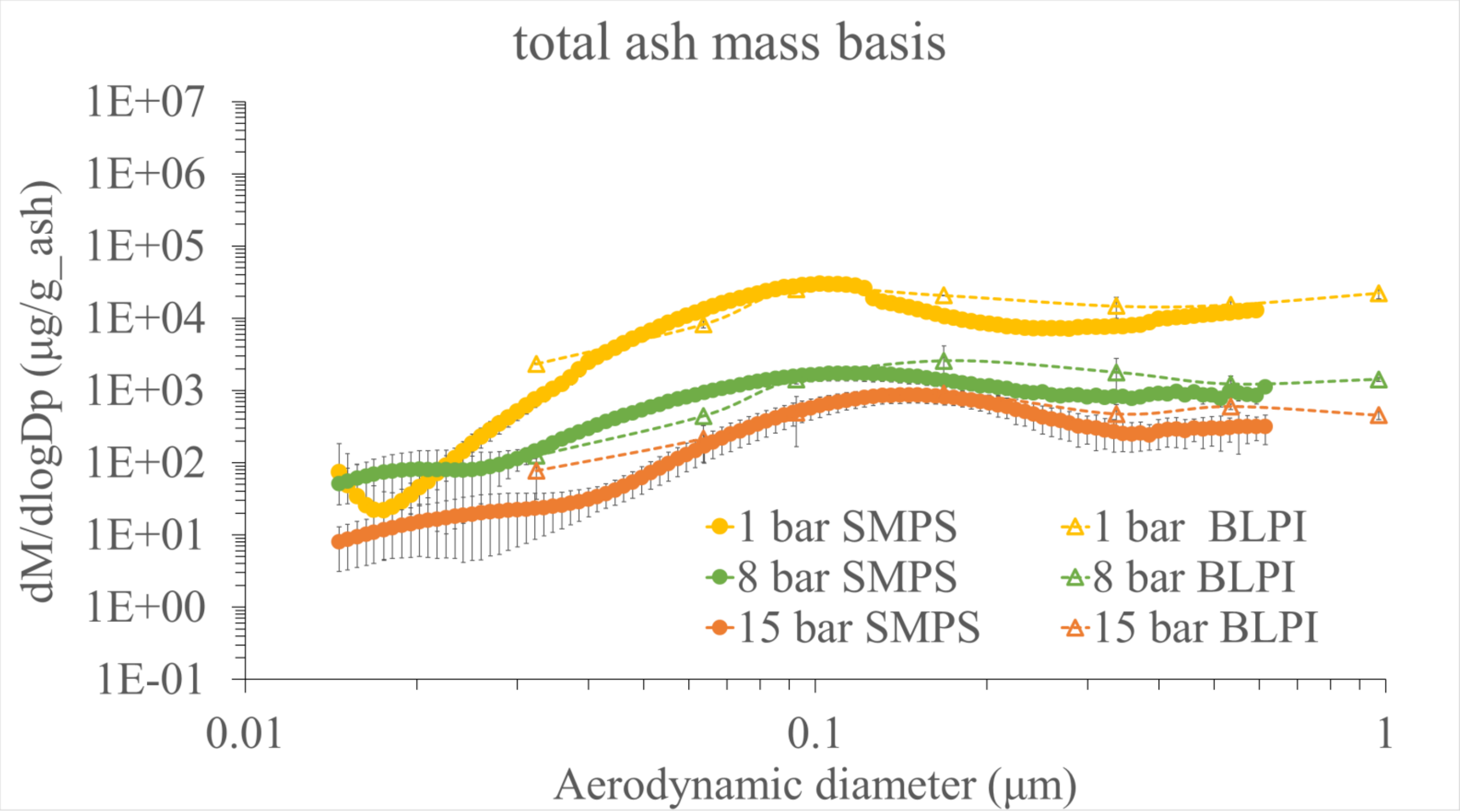


Sub-micron Aerosol Particle Size Distributions



- Concentration of sub-micron particles decreases as pressure increases
- Mode at 15 bar is located at larger diameter than 1 bar

Conclusions

- Oxy-coal combustion experiments have been carried out at 1 bar, 8 bar and 15 bar
- An ash aerosol sampling system has been devised that meets safety requirements, preserves the integrity of the reactor, and provides representative sample streams with low loss rates
- Scavenging of alkali metals by supermicron aluminasilicates leads to lower concentrations of Na and K on sub-micron particles at atmospheric pressure
- Comparisons between equilibrium calculations and measurements for alkali species indicate vaporization and condensation mechanisms are kinetically controlled
- Sub-micron ash aerosols formed at high pressure contain larger amounts of alkali metals likely in the form of sulfates
- Lower concentrations of sub-micron particles observed as pressure increases

Acknowledgment & Disclaimer

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