Characterizing Impacts of Dry Coal Feeding in High Pressure Oxy-Coal Combustion Systems

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For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

Transformative Power Generation

Project Review Meeting

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No proprietary information is included in this presentation

Motivation

Relevance

- Key second generation candidates for CO_2 capture include high temperature and pressurized oxy-firing of coal
- Application of these technologies to steam generation have potential to increase efficiency, reduce capital costs, avoid air ingress and reduce oxygen requirements
- Compared to first-generation oxy-coal combustion, high pressure oxy-coal is thermodynamically more efficient and reduces equipment size requirements
- Fuel feeding and firing system flexibility are challenges for high pressure coal and biomass fed combustion and gasification equipment
- Slurry-fed systems often have atomization and burnout problems exacerbated at high pressure
- Slurry atomization processes may be difficult to scale up
- Dry feeding has the potential to yield efficiency gains, provide better control over flame aerodynamics, improve flexibility and facilitate scale up

Program Objective

- Develop data and validate mechanisms describing heat transfer, ash deposition and corrosion in a high temperature, high pressure oxy-coal combustion system with dry coal feeding

Technical Approach

1. Design, construction and installation of a pressurized feeding system for dry pulverized coal in an entrained flow pressurized combustor
2. CFD-based guidance of burner design and pilot-scale operation of pressurized oxy-coal combustion with a dry feed system
3. Detailed measurements of heat flux and flame and material temperatures at high temperatures while firing at 300 kW and 17 bar
4. Ash aerosol measurements at 17 bar pressure experimental conditions to determine slagging and fouling propensity of the ash, and its deposition rates as a function of high pressure
5. Characterize corrosion propensity under high temperature and high pressure conditions using real time corrosion sensors
6. Refinement of CFD modeling tools to ensure accurate prediction of the impacts of high temperature and high pressure oxy-coal combustion on heat flux, ash deposition and corrosion in a commercial boiler implementation

Program Overview

Enabling Technologies for Advanced Oxy-Coal Combustion Systems

Characterizing Impacts of Dry Coal Feeding in High Pressure Oxy-Coal Combustion Systems (DFHP)

October, 2016 – September 2021

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Program Elements

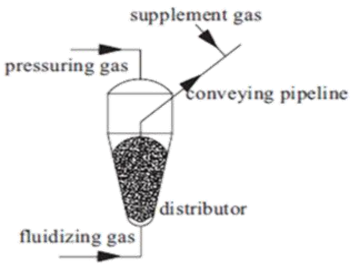
Design, construct and install pressurized dry feed system

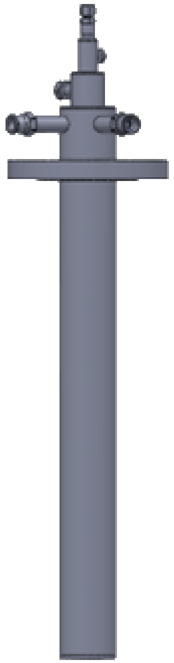
Design, construct and install pressurized burner system

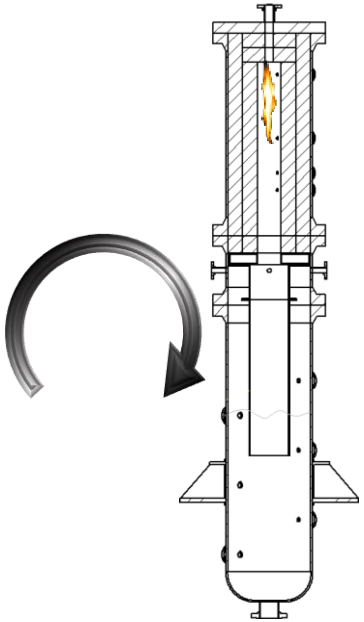
Conduct experiments at University of Utah's Entrained Flow Pressurized Reactor (EFPR)

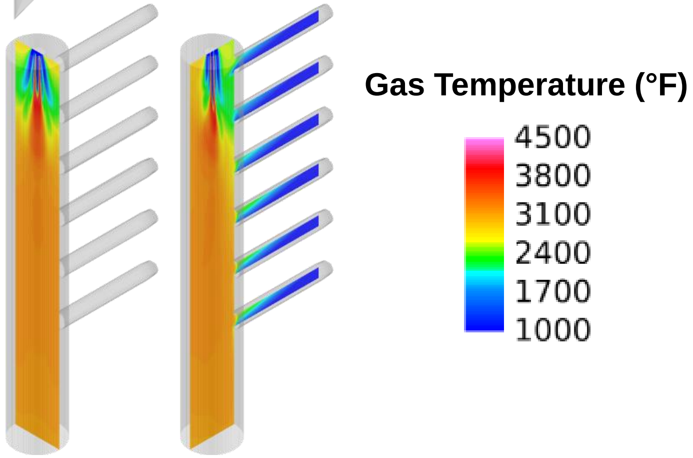
Validate simulations of high pressure oxy-coal combustion

Economic analysis and full-scale boiler scoping



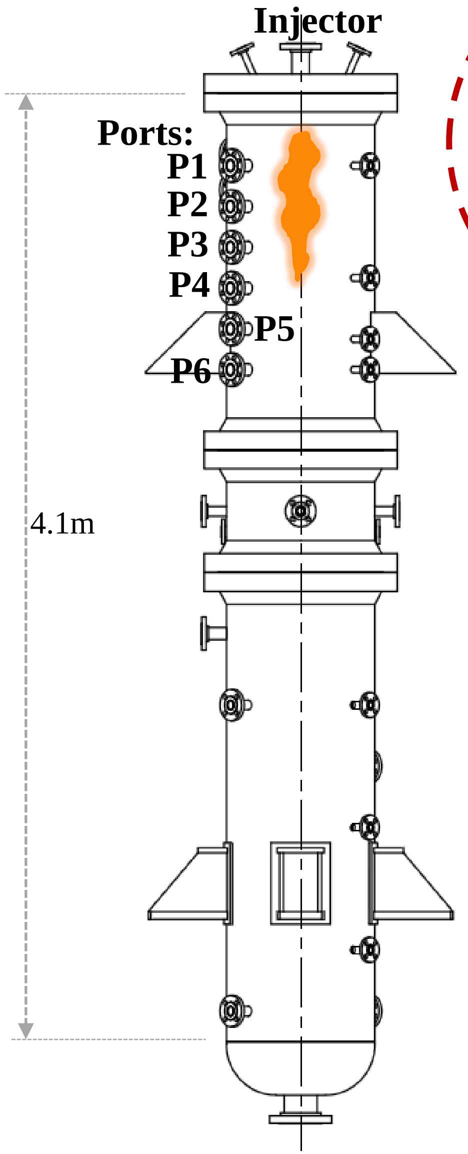


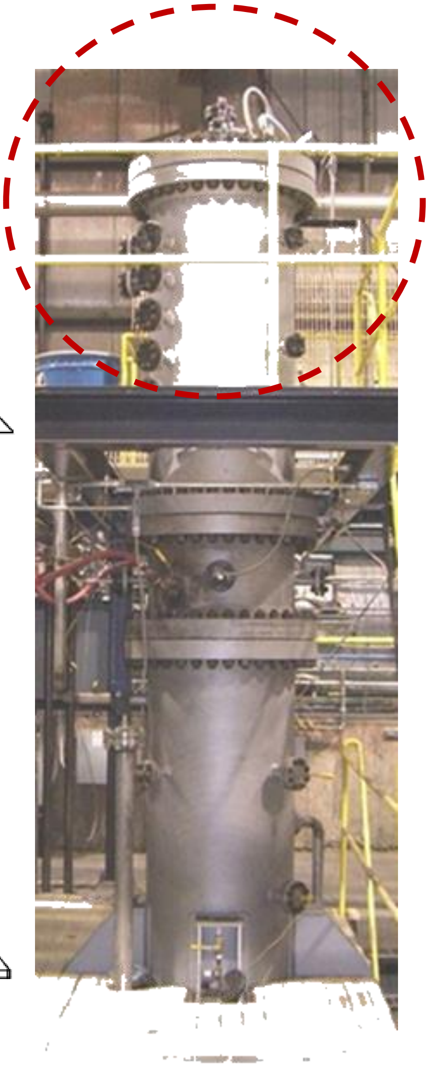


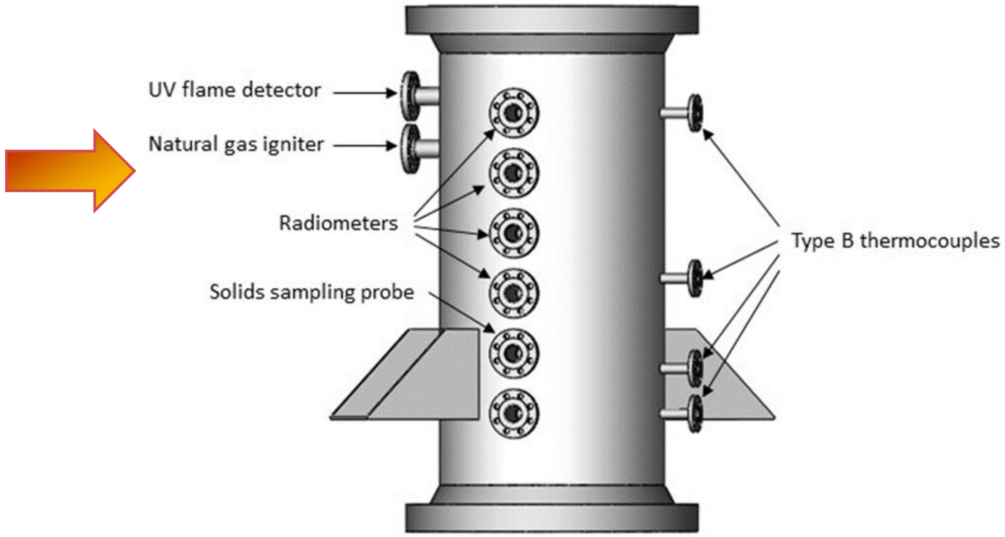


300 kW Entrained Flow Pressurized Reactor (EFPR)

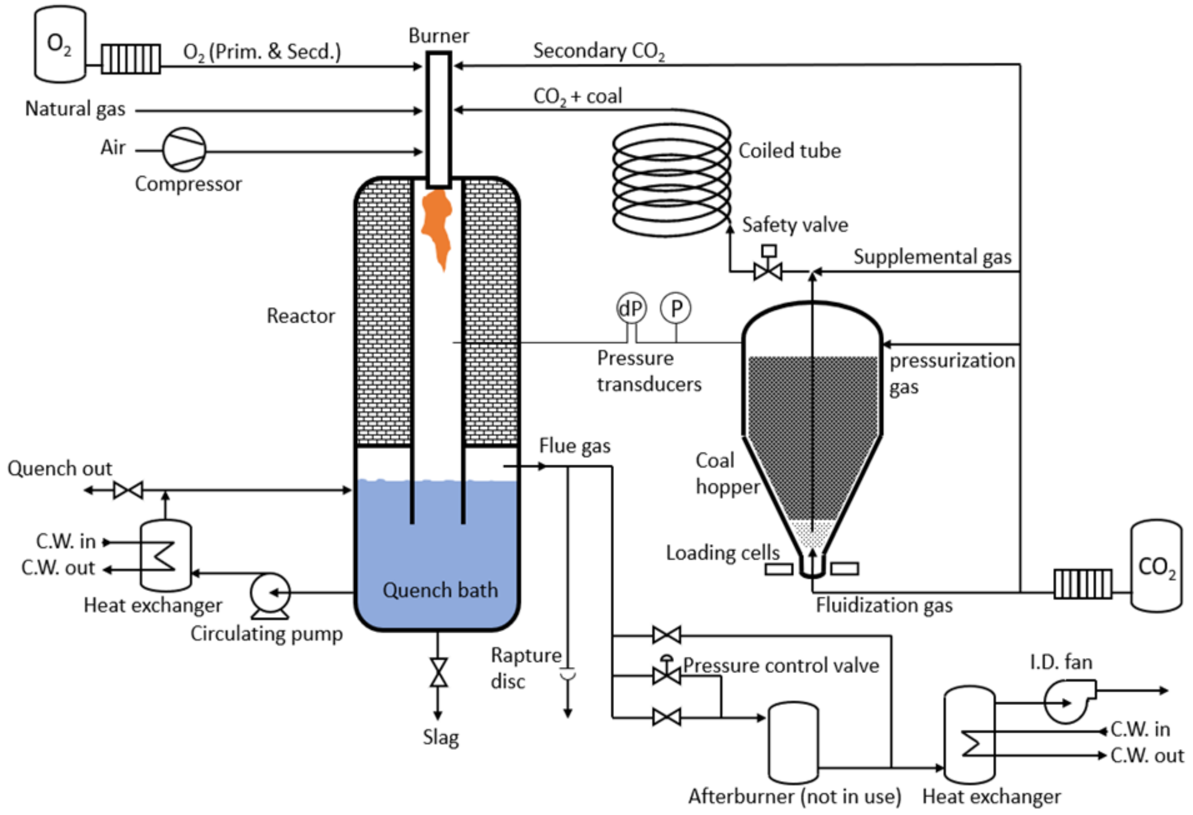
- Converted from an entrained flow gasifier
- 300 kW (rated) pilot scale
- Originally coal-water slurry feeding with pure O_2
- Down-fired, self-sustained with no external heating
- Operation pressure up to 30 bar

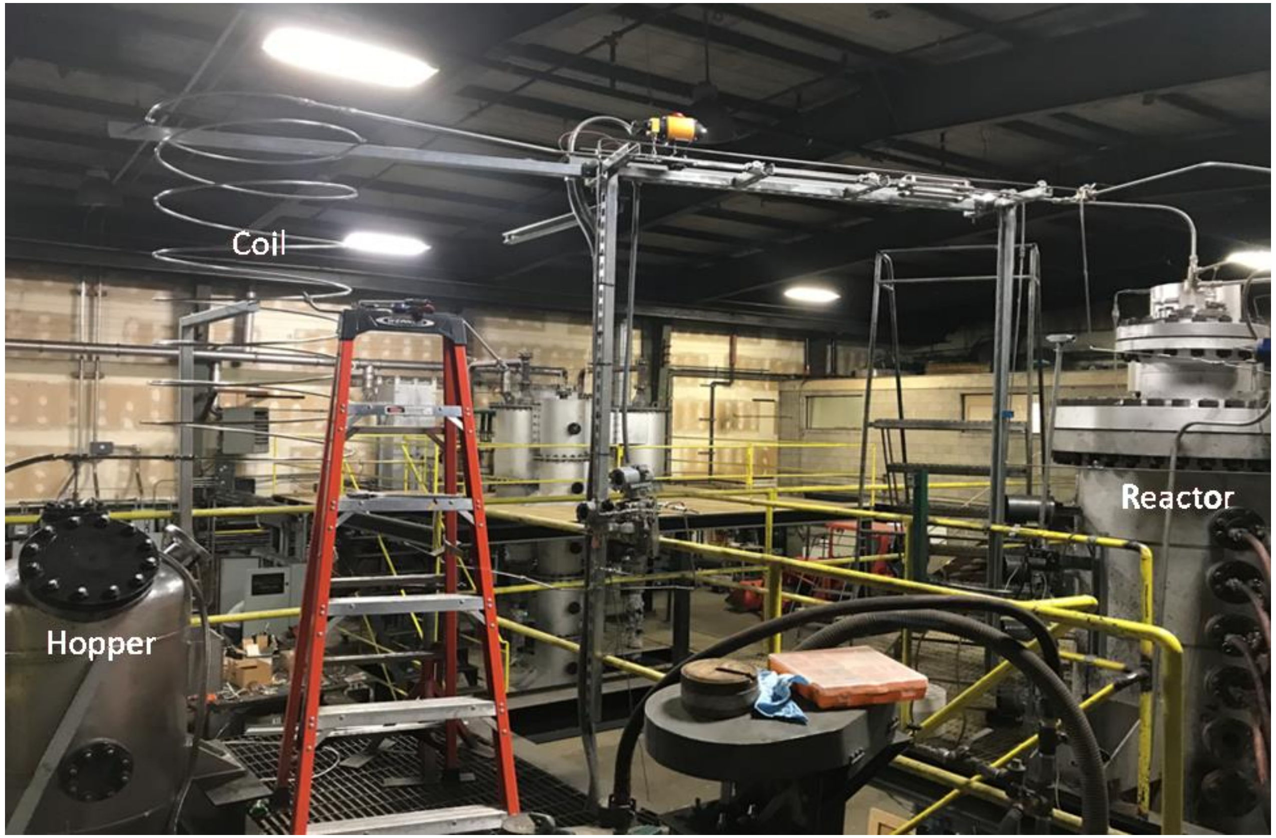






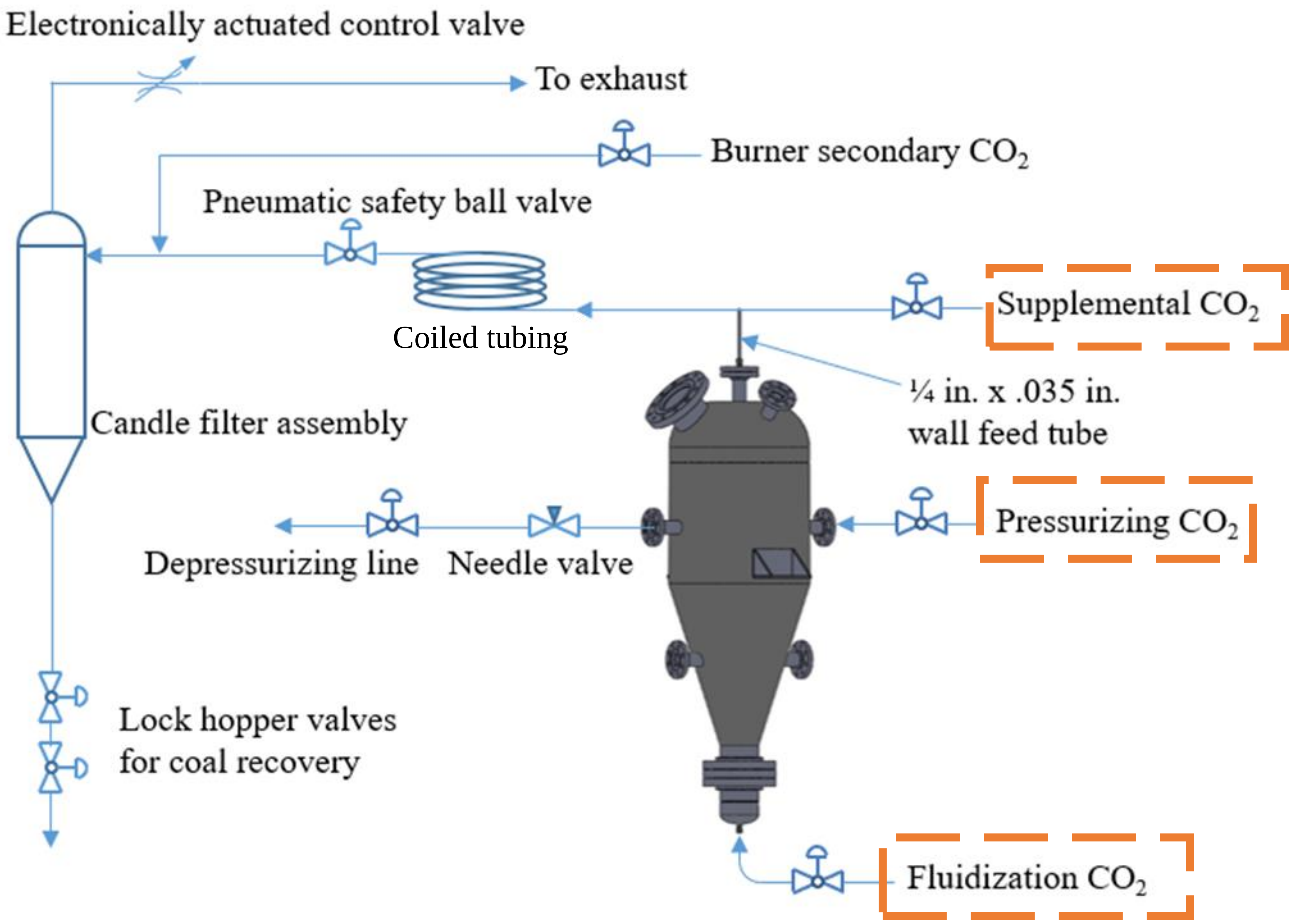
Integration of Dry Feed System

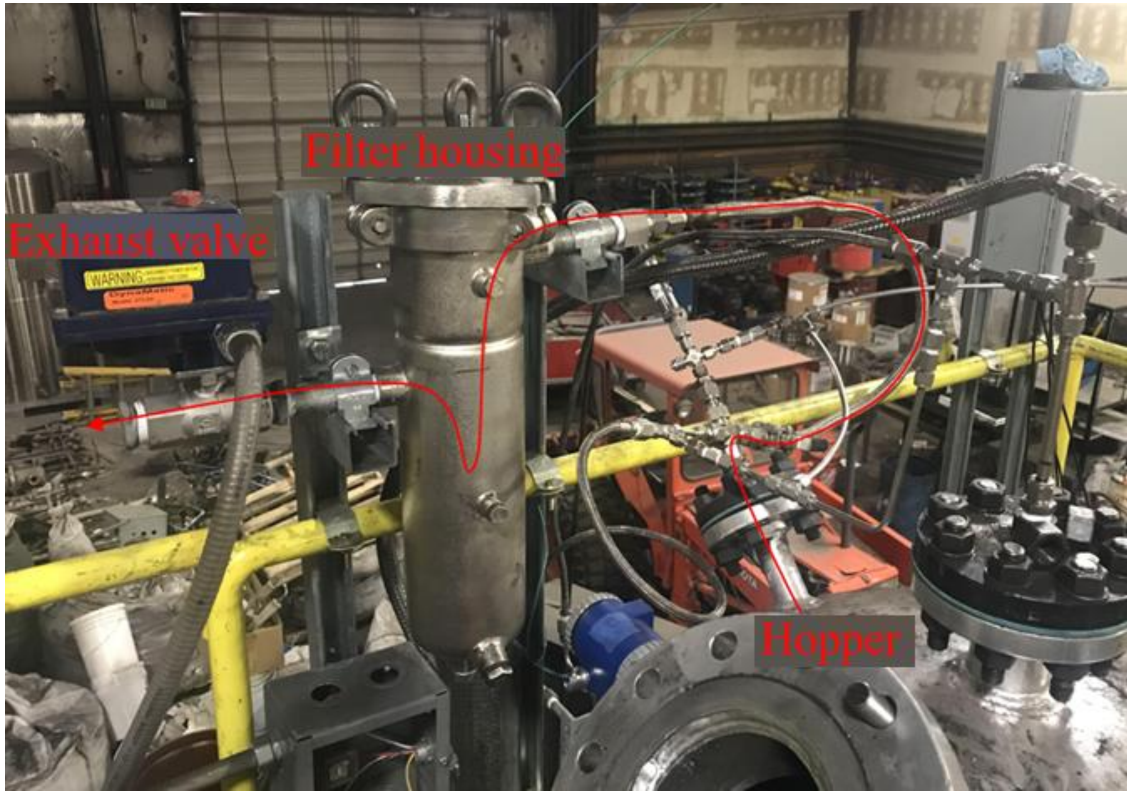




Testing Coal Transport at High Pressure

Non-reacting Test Apparatus at the University of Utah

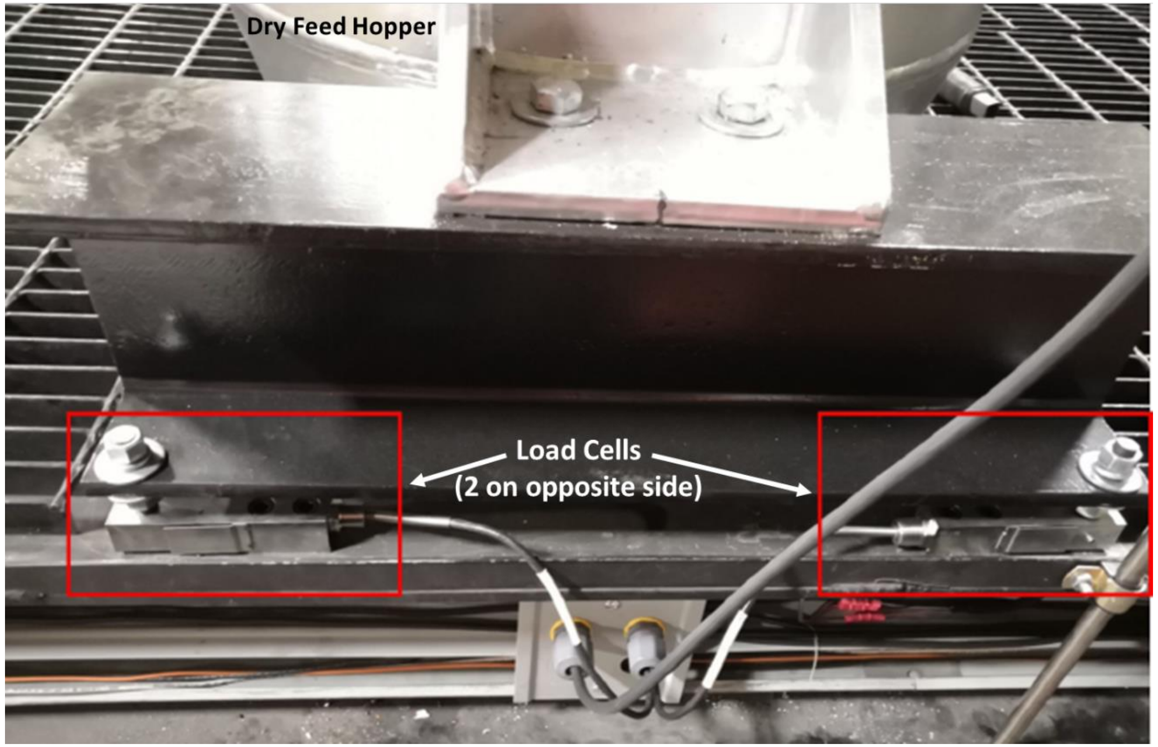




Testing Coal Transport at High Pressure

Coal Flow Measurement and System Pressurization

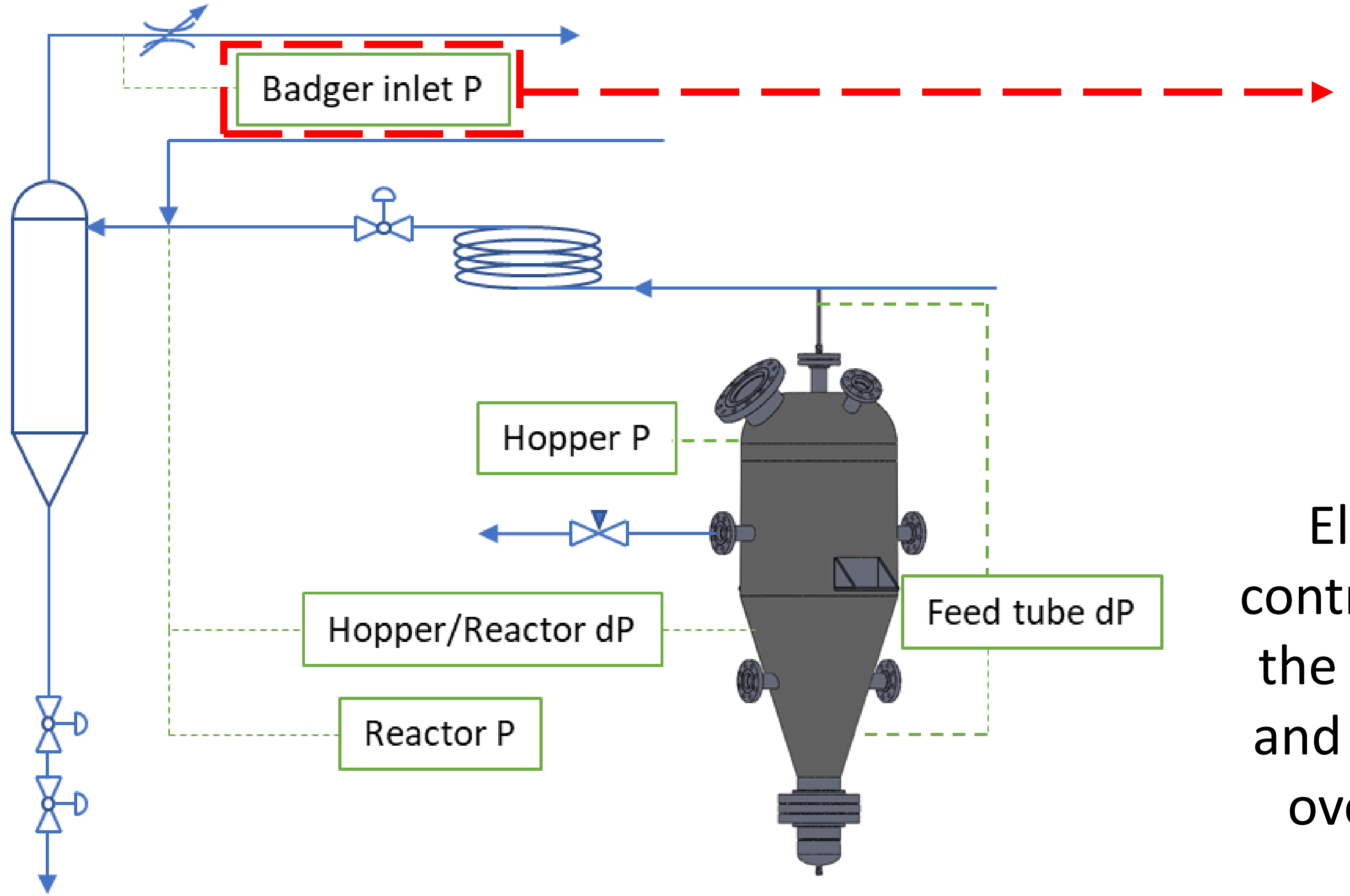
Dry Feed Hopper Mounted to Load Cells



Candle Filter Assembly

Individual Stainless Steel Candle Filter

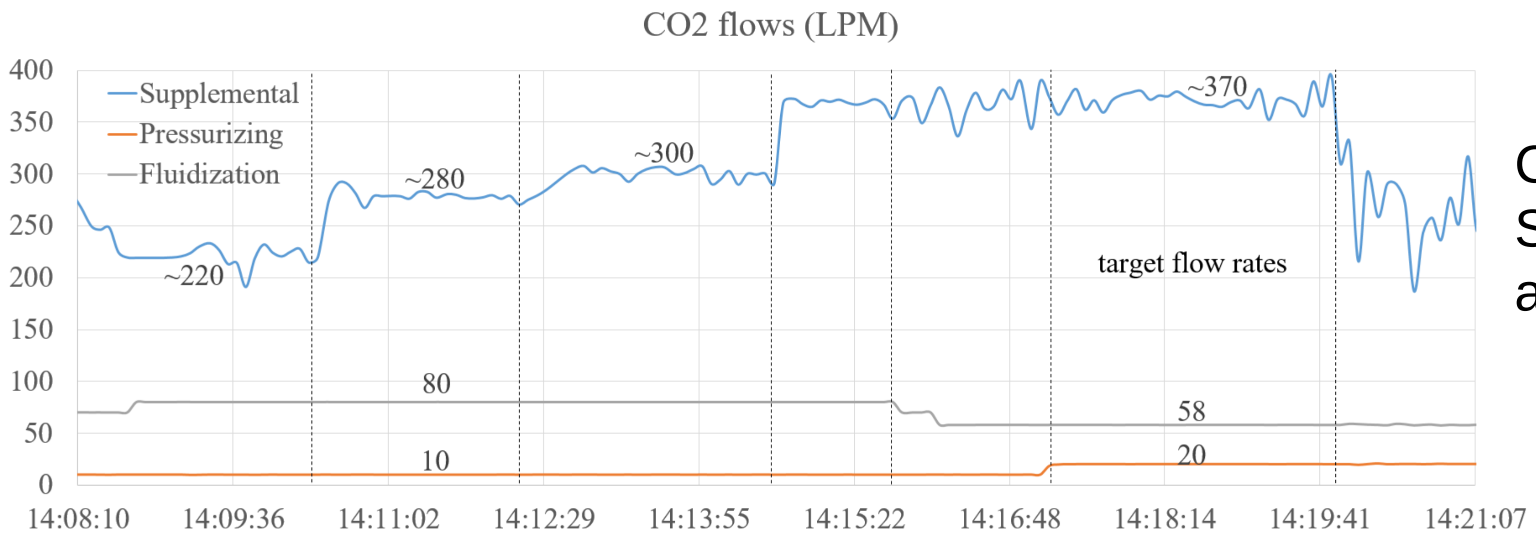
Dry Feed System Pressure Measurement Locations



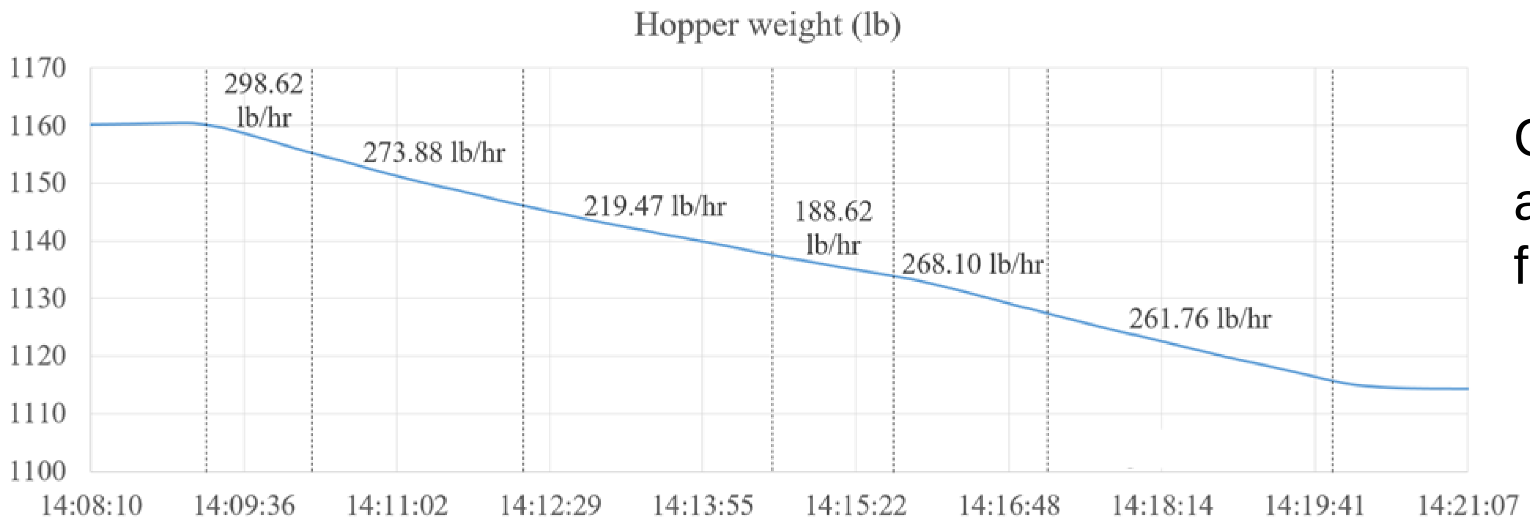
Electronically actuated control valve used to control the pressure of the reactor and enabling better control over the hopper/reactor pressure drop

Testing Coal Transport at High Pressure

Coal Flow Rate as a Function of CO_2 Flow Rates



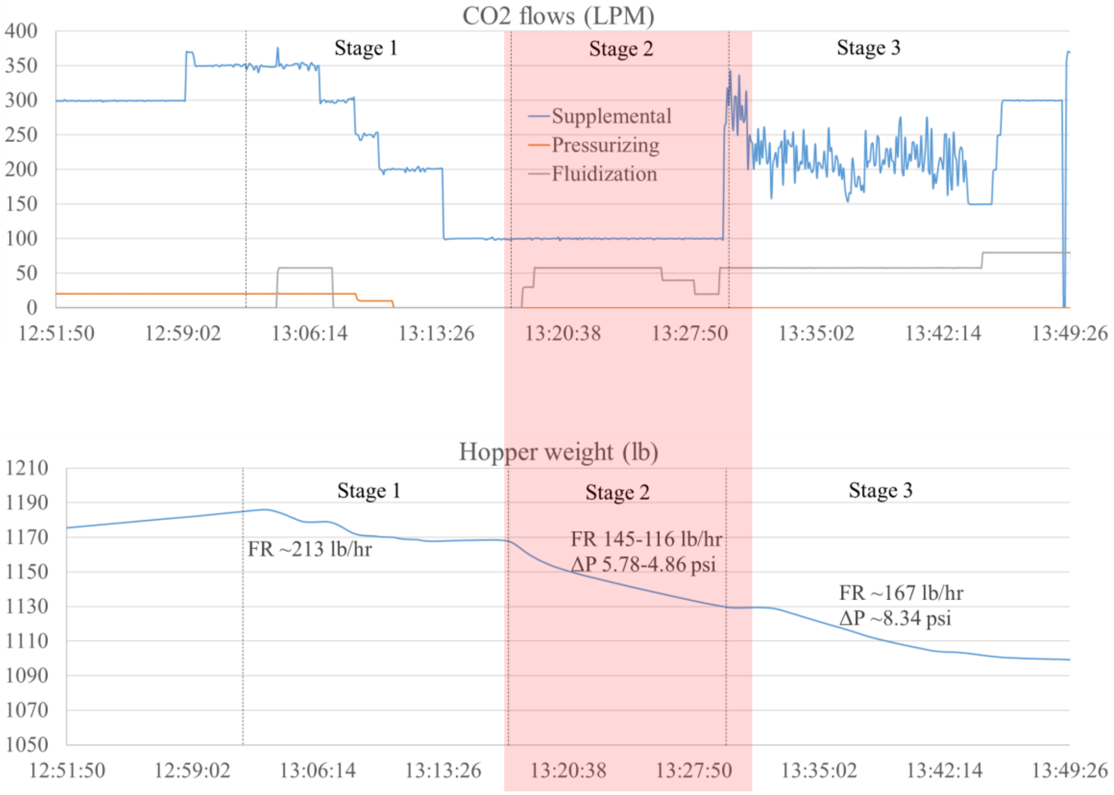
CO_2 Flow Rates for Supplemental, Pressurizing and Fluidization streams



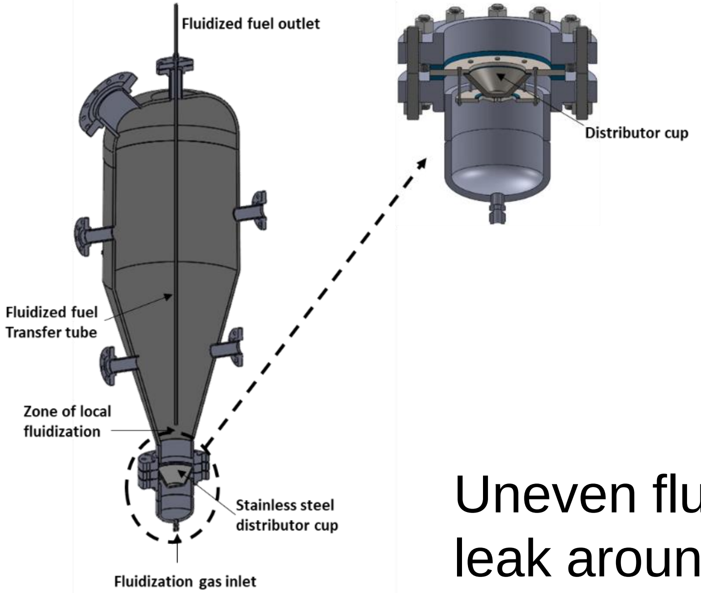
Corresponding coal flow rates are higher than the target value for the 200 kW firing rate

Pulverized Coal Fluidization in the Dry Feed Hopper

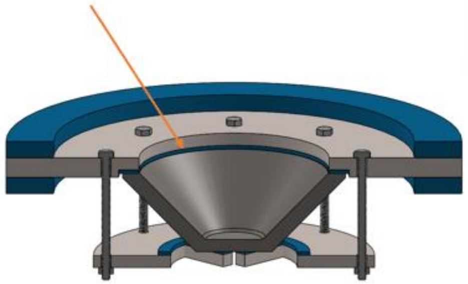
Tests to calibrate CO_2 stream flows to achieve target coal flow indicated an improvement with low fluidization flow



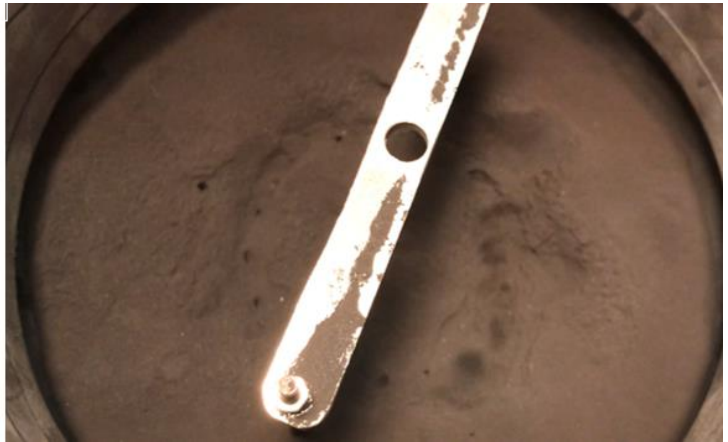
Leakage around the distributor cup was identified as the cause for poor fluidization



Rubber gasket that does not seal



Uneven fluidization due to leak around cup perimeter

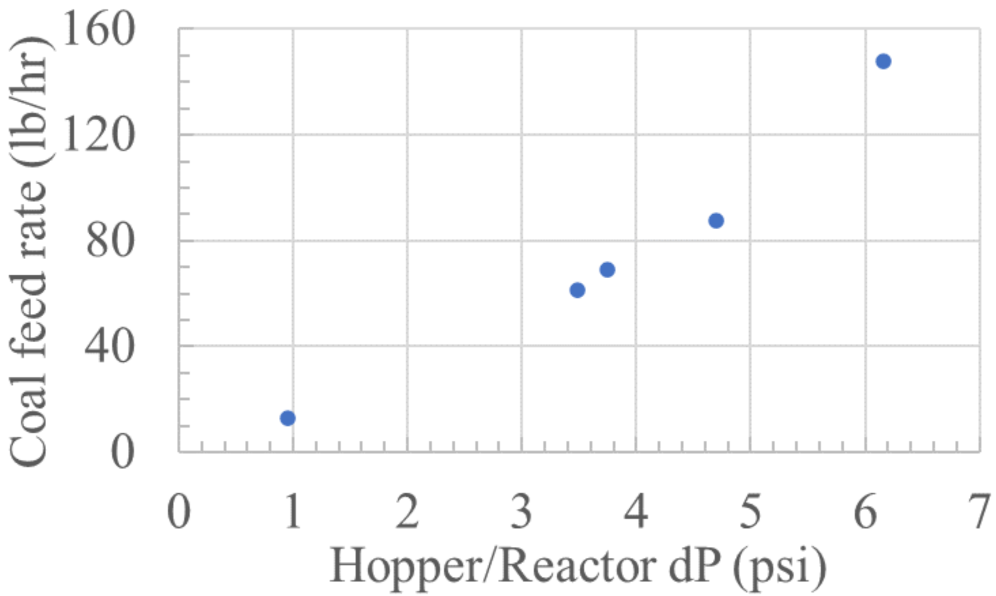


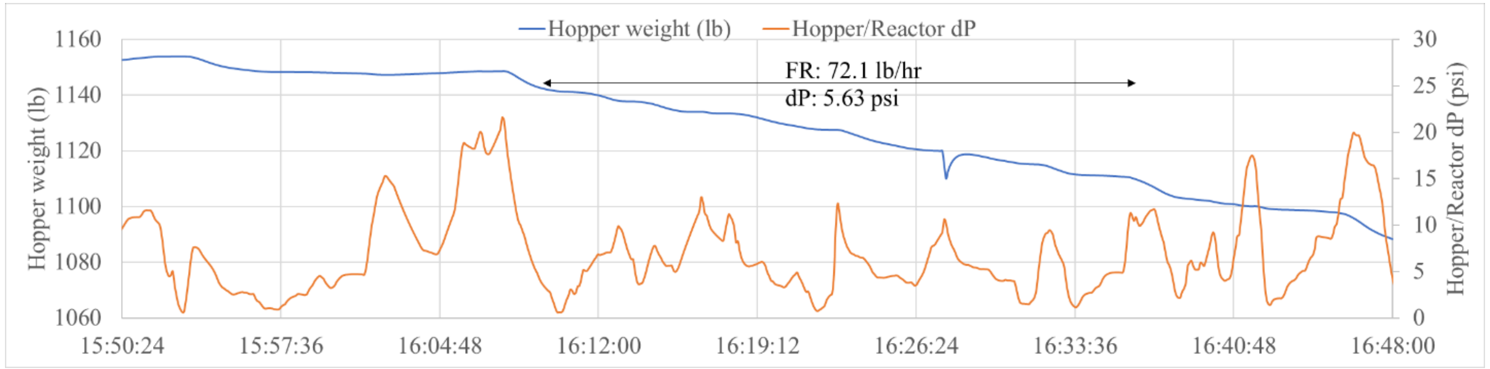
Achieving Target Coal Flow Rates

Welded cup flange assembly

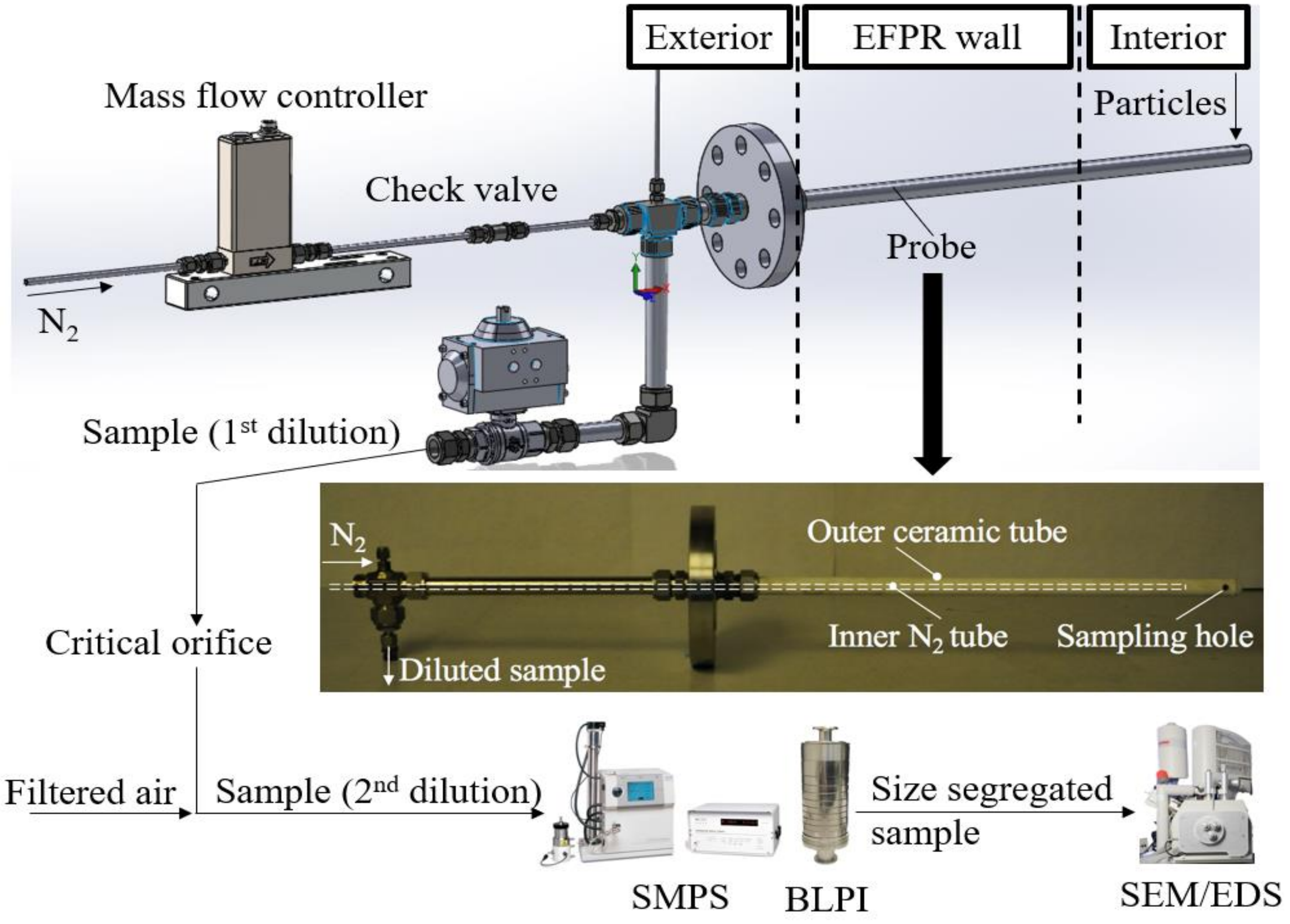
Improved fluidization above cup

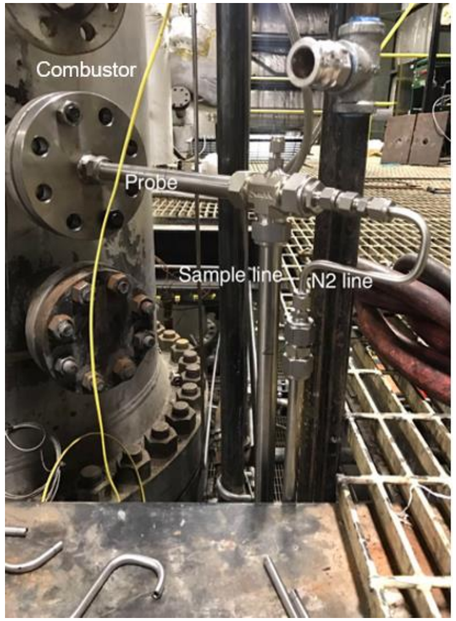
Coal flow rate control is a function of the feed hopper to reactor pressure difference





High Pressure Aerosol Sampling System





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 2nd generation oxy-coal combustion systems

Oxy-Fuel Combustor (OFC)

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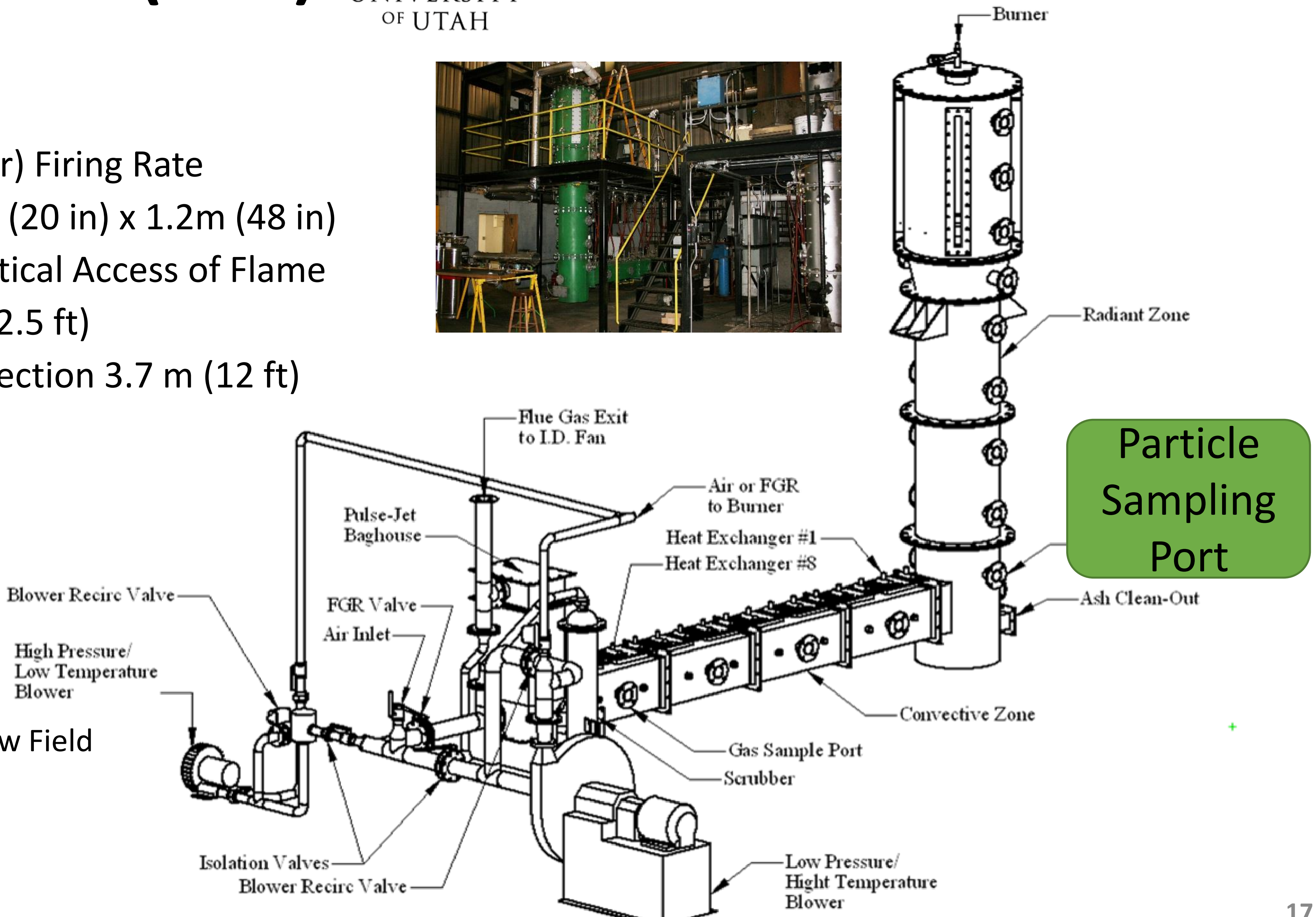
Specifications

- 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)

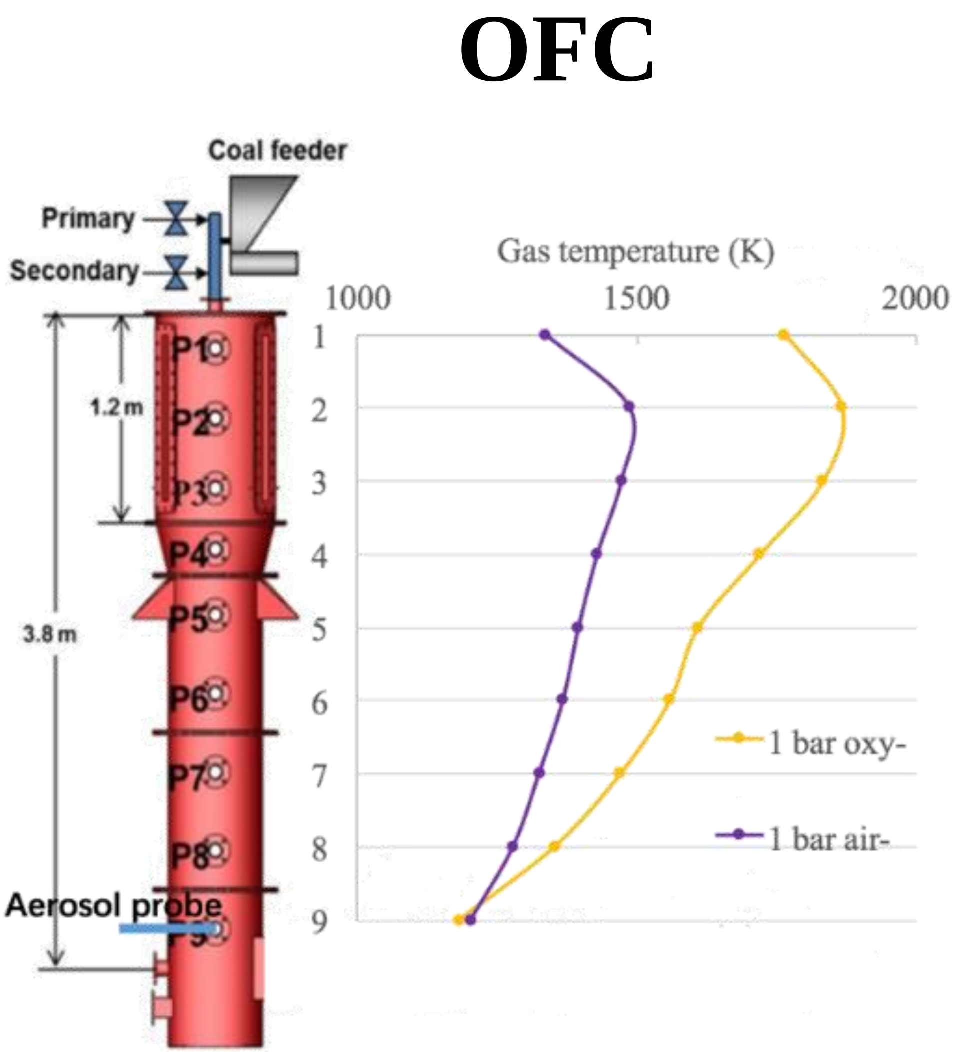
Research

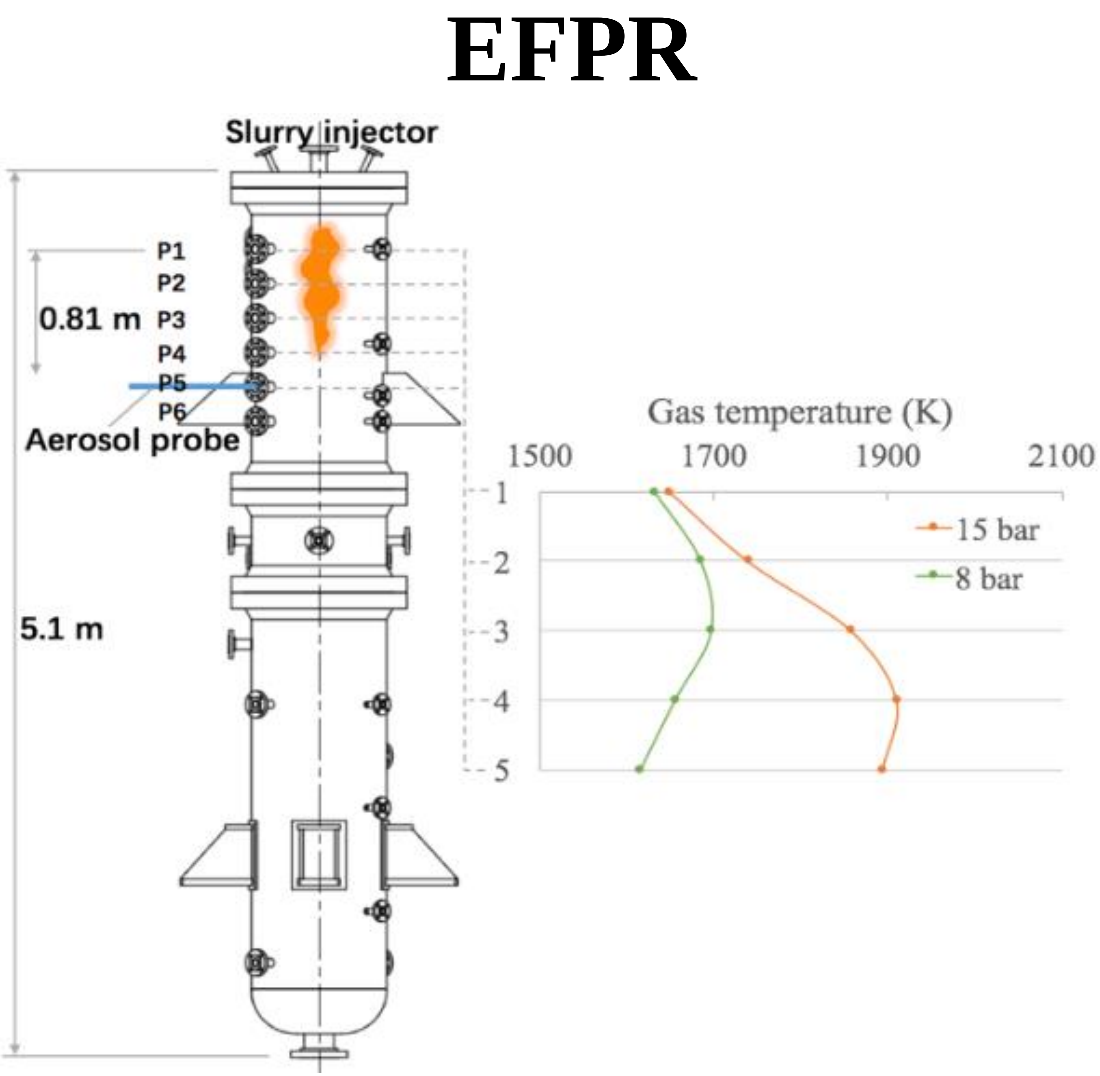
- Ash Formation
  - Aerosols
  - Deposition
  - Trace Elements
- Sorbent Development
- Optical Diagnostics
  - Flame, Radiation & Flow Field



Comparison of OFC and EFPR

Gas Temperature Profiles



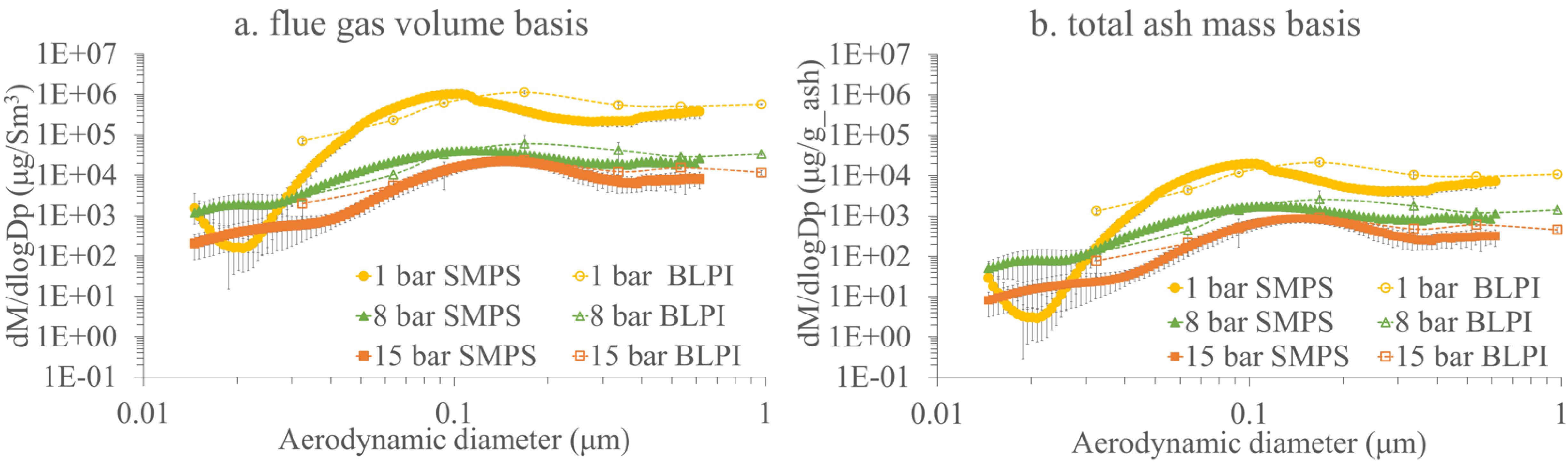


Combustion Conditions

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

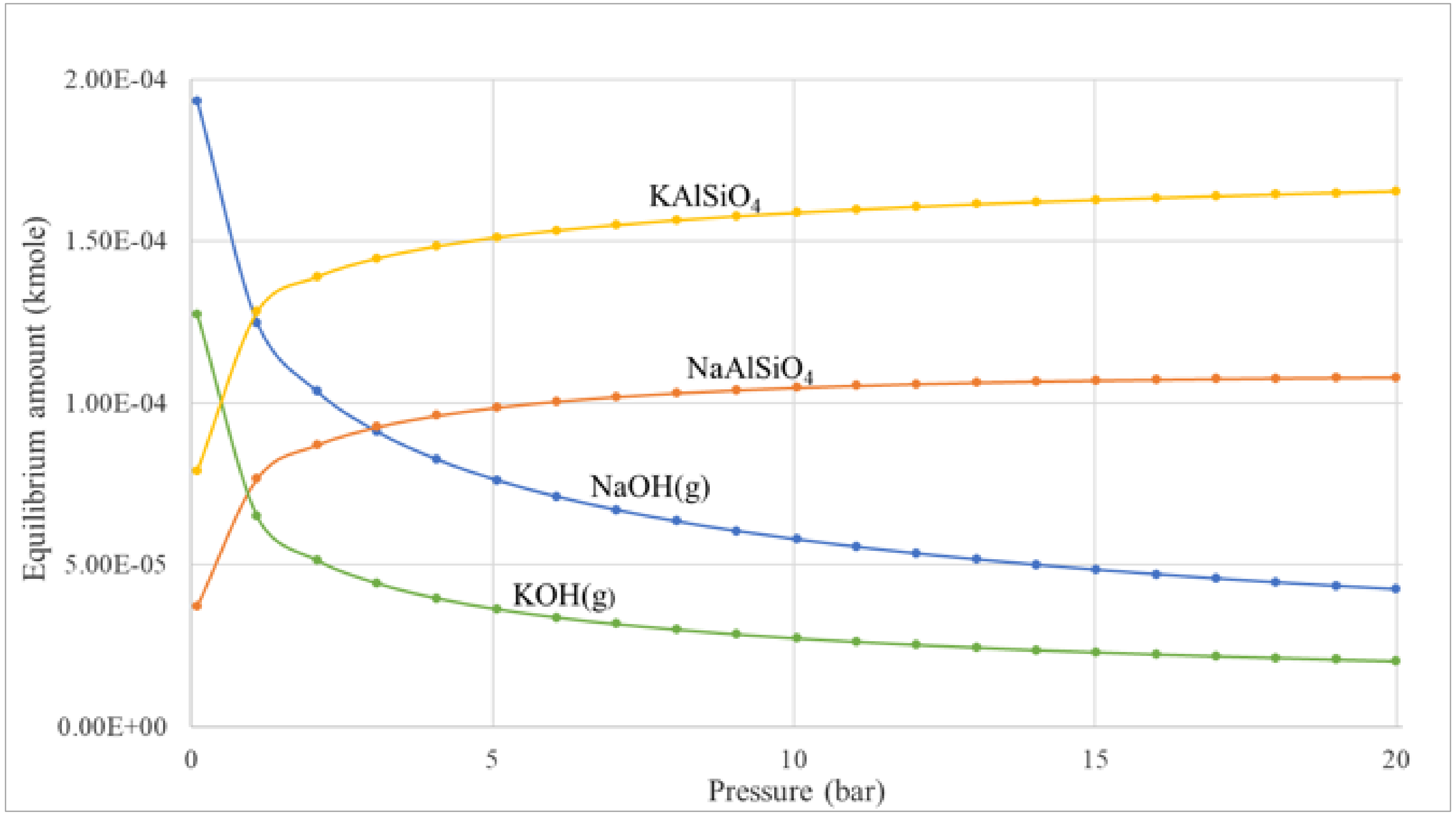
Particle size distributions 1, 8 and 15 bar



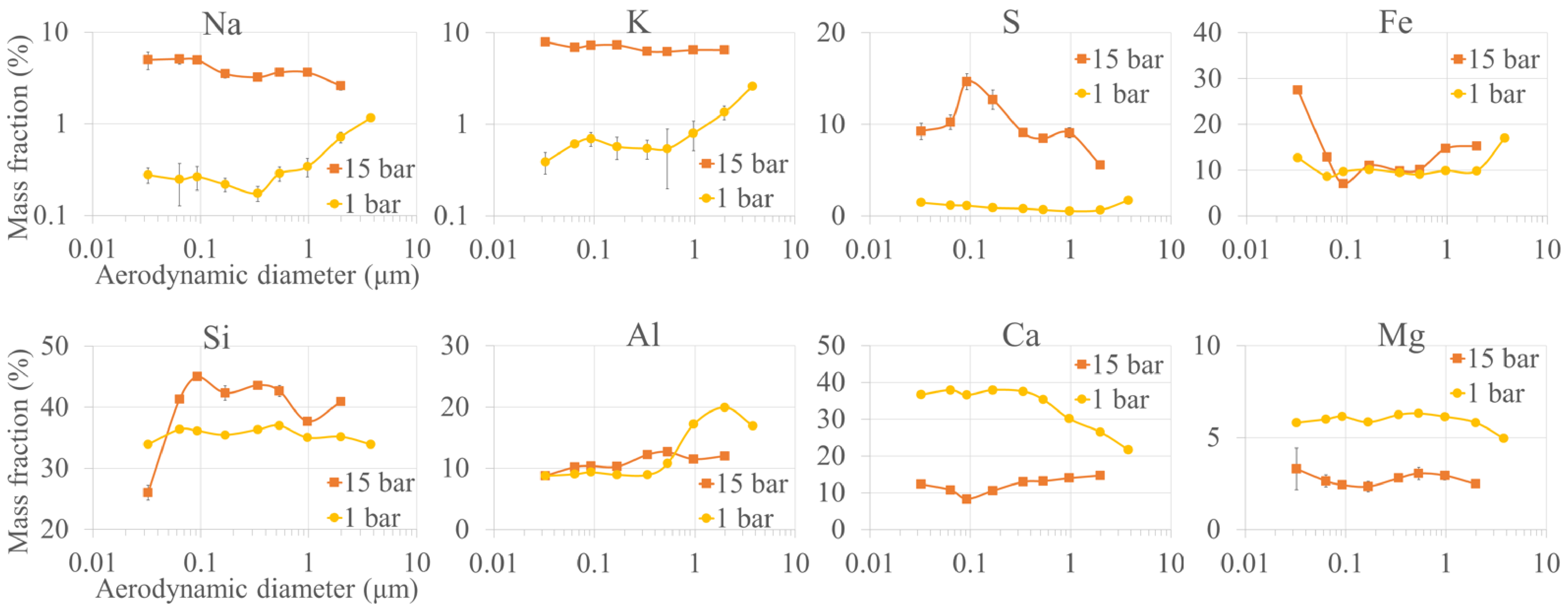
Sub-micron particle size concentration in flue gas (a) and sub-micron particle yield per g-ash (b) are both diminished at elevated pressures

Impact of Pressure on Metal Volatilization

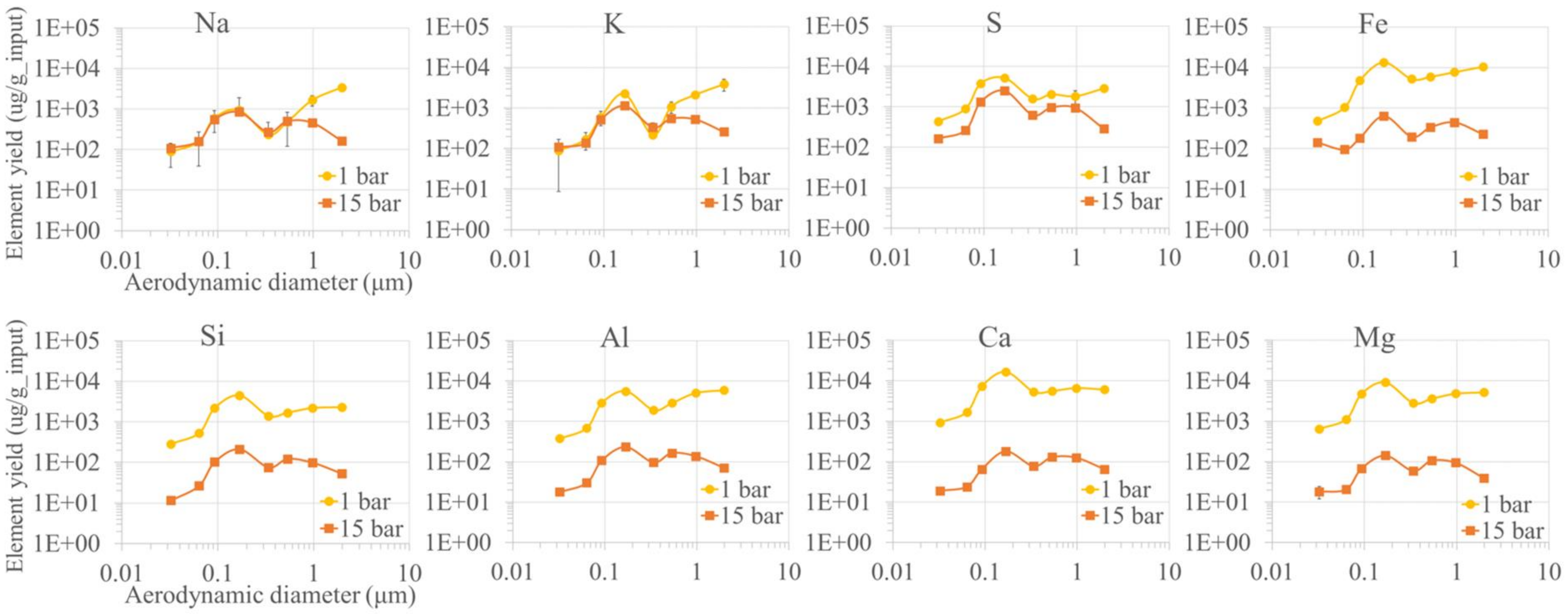
Equilibrium Calculations



Raw data on size-segregated sub-micron particle compositions



Size-segregated elemental yields



Little effect of pressure on semi-volatile metals (K and Na) and S. Large reduction in yield at high pressure for non-volatile metals (Fe, Si, Al, Ca and Mg). Suggests small fraction of refractory metals are organically bound and are “orphaned” rather than vaporized during char oxidation.

Next Steps

Market Benefits/Assessment

- Demand for the proposed technology has significant promise in the U.S. as power producers seek technologies for CO_2 capture, utilization (e.g., enhanced oil recovery) and storage
- Certain U.S. utilities are actively pursuing collaboration with academia and industry experts to explore strategic alternatives for effective utilization of coal
- Immense demand for coal overseas along with viable technologies to address CO_2 emissions

Technology-to-Market Path

- Efficiency gains, fuel flexibility, and opportunities for scale up present a great value proposition for U.S. utilities
- REI is seeking to leverage its relationships with U.S. utilities, international clients, project partners, and industry stakeholders to actively pursue commercial opportunities within the U.S. and internationally
- Pilot-scale experiments will seek to demonstrate the technical feasibility of integrating a batch dry feed system into a pressurized oxy-coal system
- Continued research is necessary to address challenges associated with:
    1. Continuous steady operation vs. batch
    2. Design of a steam generator incorporated into a pressurized oxy-coal combustor with dry feed
    3. Application at larger scales

Summary

- Design and fabrication of the pilot-scale dry feeding system has been completed
- Non-reacting coal transport test have been carried out to address the key technical challenge of consistently feeding dry coal in a pressurized reactor
- Maldistribution of fluidization CO_2 identified as the cause for coal flow rates above target values; and subsequently corrected
- The coal flow rate is highly dependent on dry feed hopper/reactor pressure drop.
- A series of tests showed success in reaching the target coal flow rate, but the relatively low hopper/reactor pressure drop continues to present operational challenges for consistent coal feeding
- Advanced aerosol characterization in EFPR successfully applied in preceding coal slurry-fed operation and readied for dry-fed experiments
- While the dry feed system has been calibrated, continued research on impacts of pressure on ash aerosol formation have been carried out and show measurement data did not follow equilibrium predictions on effect of pressure on metal volatilization
- Elevated pressure, at comparable peak temperatures, greatly diminished the sub-micron portion of the total fly ash – from 1.8% at 1 bar to 0.09% at 15 bar.
- Results suggest metal release mechanisms for Na and K differ from those of the more refractory metals in the second group of the periodic table
- Future work on the effects of pressure on semi-volatile metals and on organic forms of refractory metals, such as in petroleum coke, might yield additional useful insights on sub-micron aerosol formation mechanisms in general

Acknowledgment & Disclaimer

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