Development Of Enabling Technologies For A Pressurized Dry Feed Oxy-coal Reactor

Project Review

DE-FE0029157

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Transformative Power Generation Virtual Project Review Meeting
May 11, 2021

Project Overview

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- *Objective:* Develop technologies and data that will enable design and operation of a pressurized oxy-coal combustor
- $1.4M program ($1.1M DOE, $0.3M cost-share)
- 5-yr program (10/1/16 – 9/30/21)
- Team
  - Brigham Young University (Adams, Fry, Tree, students)
  - Reaction Engineering International (REI)
  - CPFD Software

Technology Deliverables

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- 100 kW_{th} 20-bar pressurized oxy-coal reactor
- Scalable pressurized dry coal feed system
- Scalable O_2-CO_2-coal burners/firing systems for diffusion flame and flameless combustion
- Measurement data
- Mechanistic process model to guide reactor scale-up and plant integration

POC System Overview

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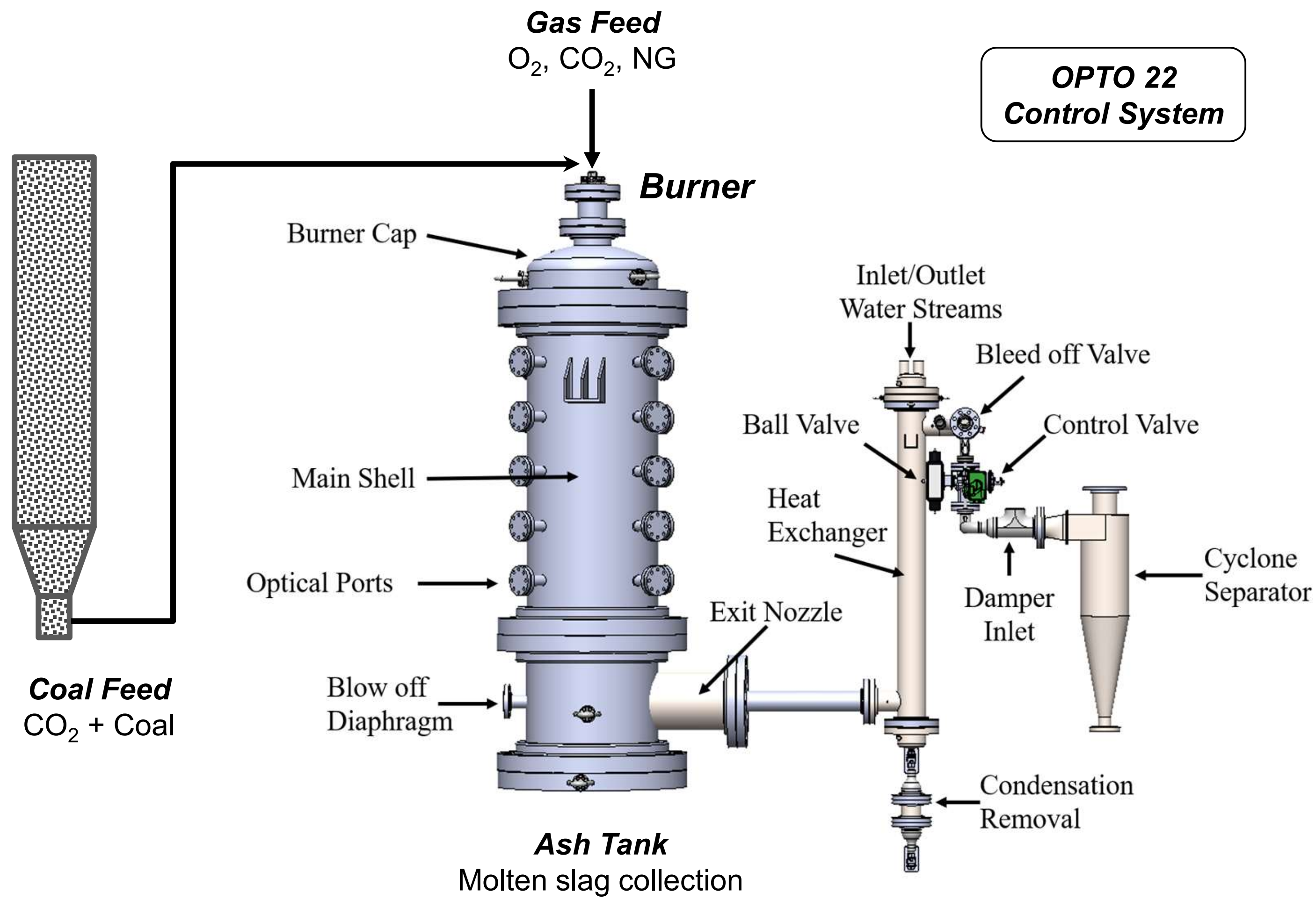

Coal Feed Design Concept

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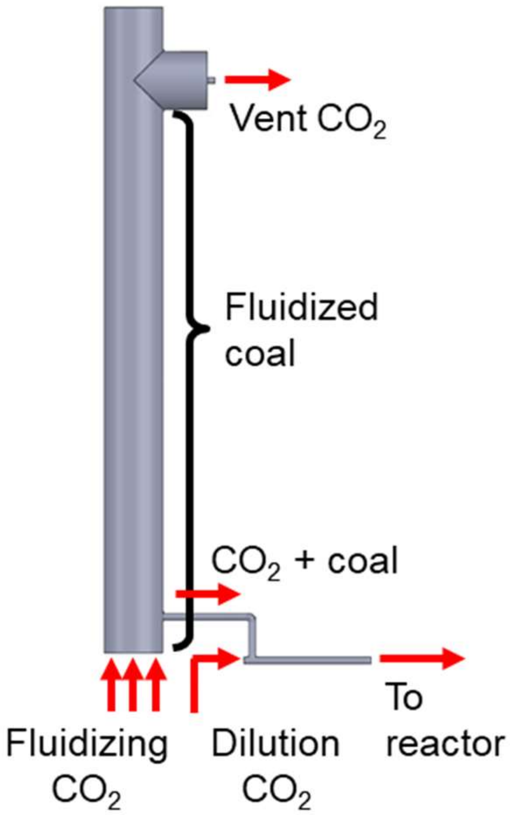
- Modeled with Barracuda CFD software
- Fluidize coal in hopper for transport; add dilution CO_2 as needed
  - Sufficient coal flow and CO_2–to-coal ratio
  - Decoupling of fluidization and dilution flows
  - Flow sufficiently steady for burner operation
  - Sensitive to gas inlet design
- Piping system has roping

Design Concept



Fluidized Bed Design

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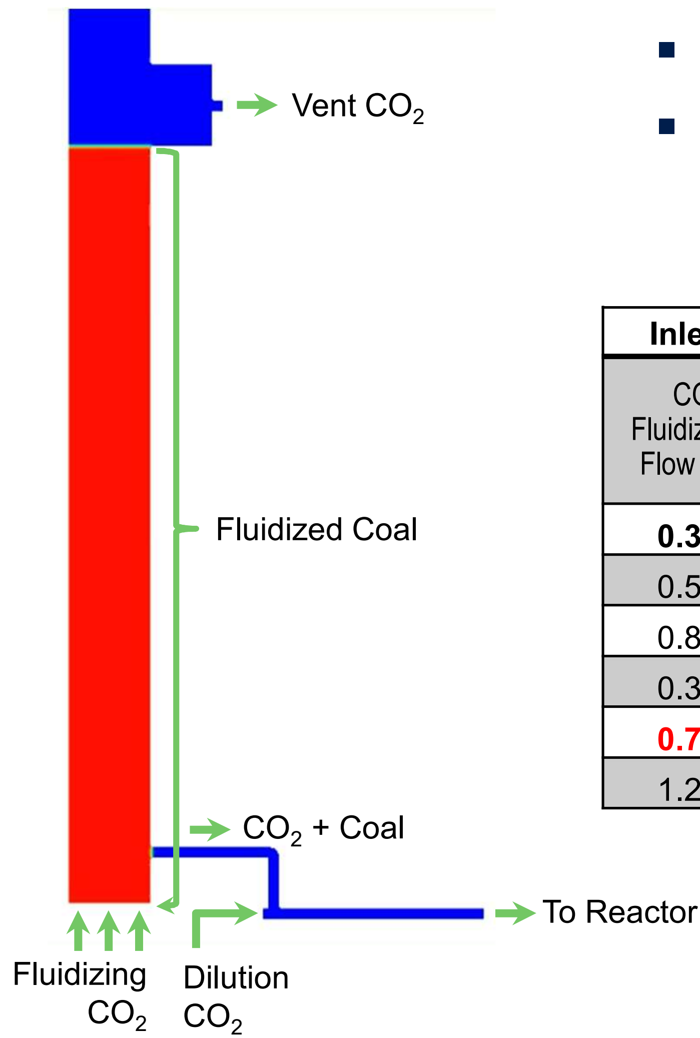
Barracuda CFD Modeling of design concept

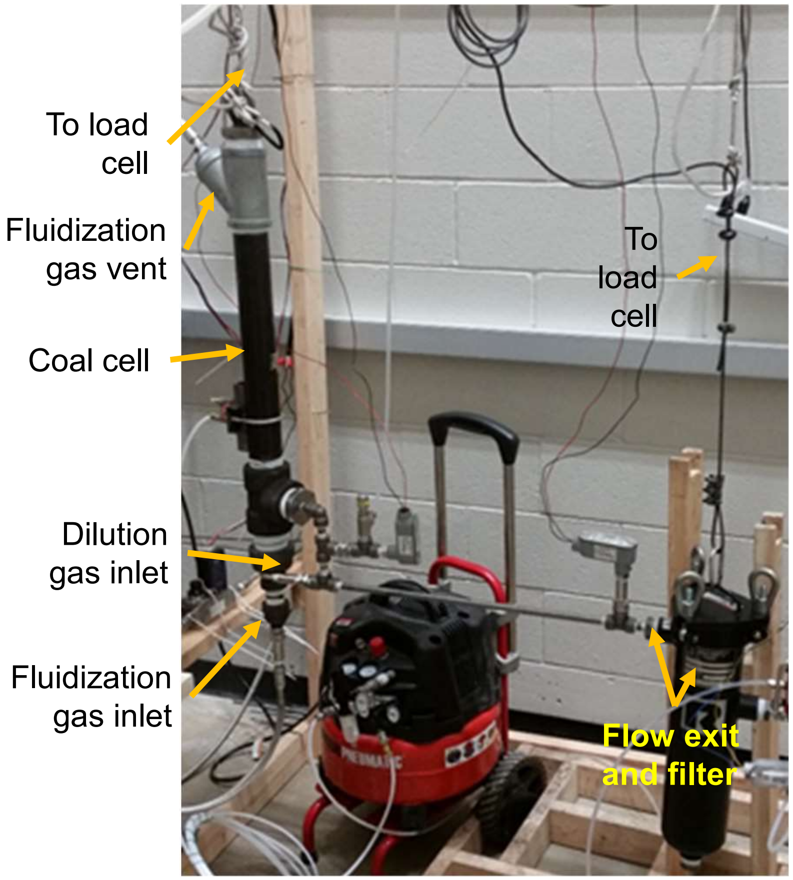


- CO_2 fluidizes coal in hopper
- Mixture transported to horizontal pipe
- Dilution CO_2 added in pipe

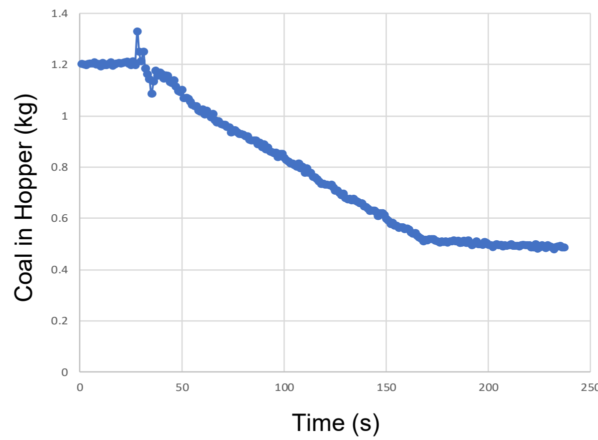
Inlet A	Outlet C	Outlet E	Inlet B	Outlet D	
CO_2 Fluidization Flow (g/s)	CO_2 Flow Through Vent (g/s)	CO_2 Flow Exiting Hopper (g/s)	CO_2 Dilution Flow (g/s)	**Coal Flow at Exit (g/s)**	Exit CO_2 to Coal Ratio
0.384	**0.034**	**0.350**	**3.350**	**5.757**	0.64
0.500	**0.150**	0.350	3.234	**5.712**	0.63
0.850	**0.500**	0.350	3.350	**4.933**	0.75
0.384	0.034	0.350	**6.700**	**5.985**	**1.18**
0.734	0.034	**0.700**	3.000	**10.588**	0.35
1.200	**0.500**	0.700	3.000	**11.130**	0.33

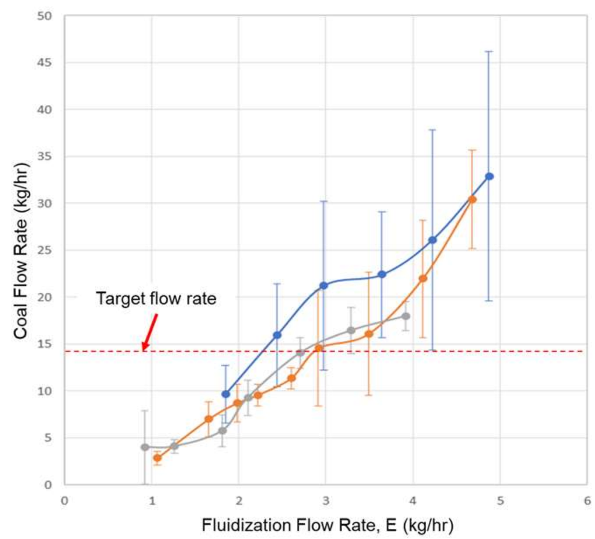
Bench-Scale Test Feeder

Bench-Scale Feed System



Testing Validates Concept





Full-Scale Coal Feeder

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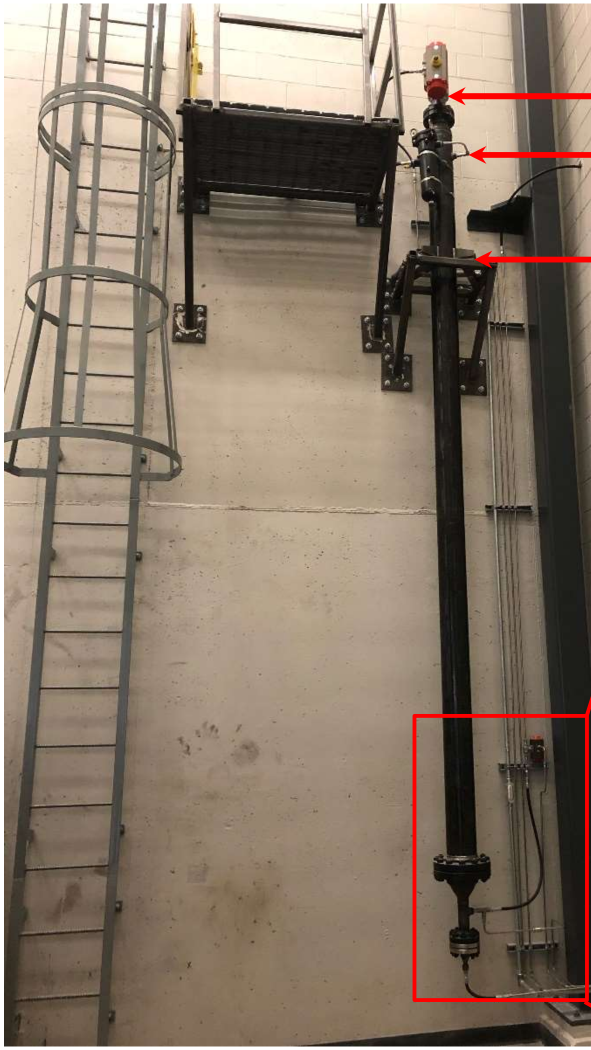
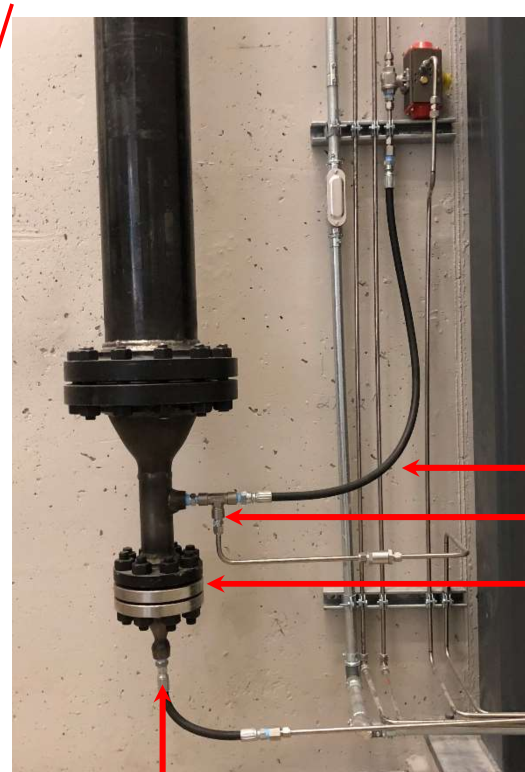
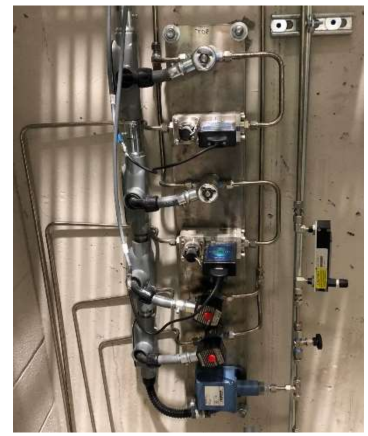
- ~13.6 kg/hr, 6 hrs
- Hydrostatic Testing to 34 bar
- Load-cells calibrated





Feeder Controls



Flame Types

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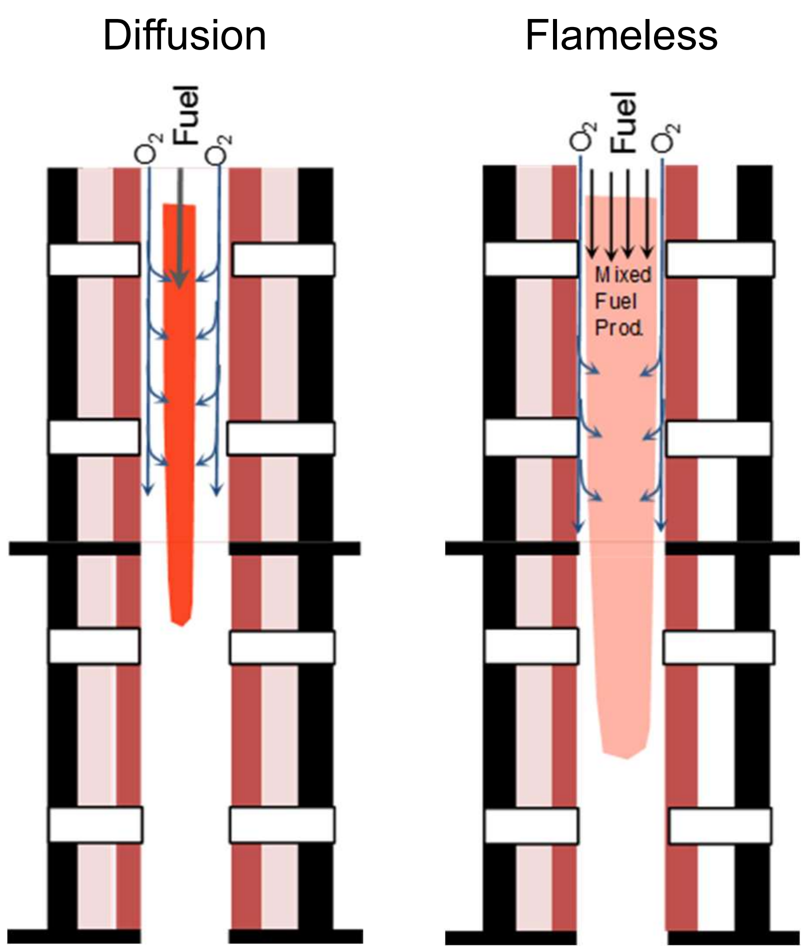
- Diffusion flame
  - Coal concentrated in center
  - Currently installed
- Flameless combustion
  - Coal distributed at inlet
  - Future design
- Design approach
  - Previous oxy-coal burner design and testing experience
  - CFD modeling of reactor combustion and heat flux



Burner Concepts

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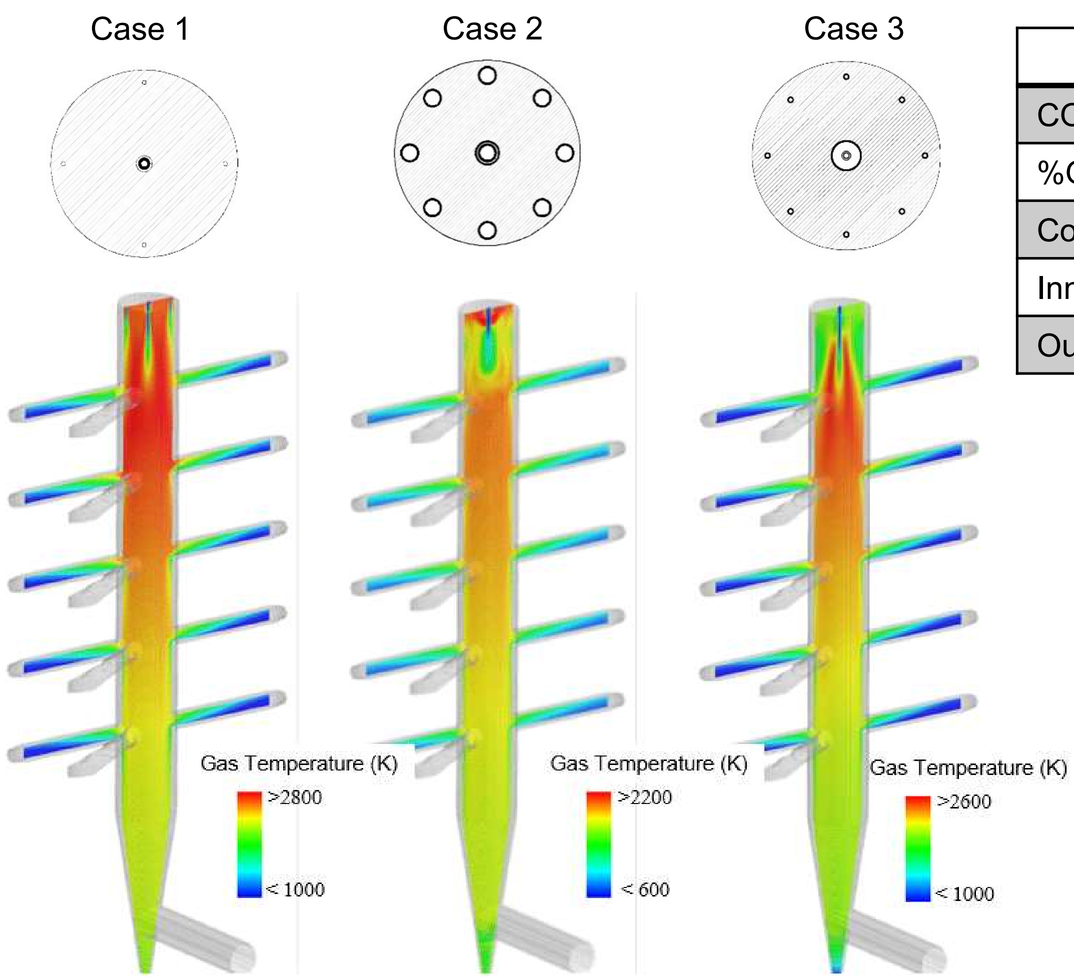


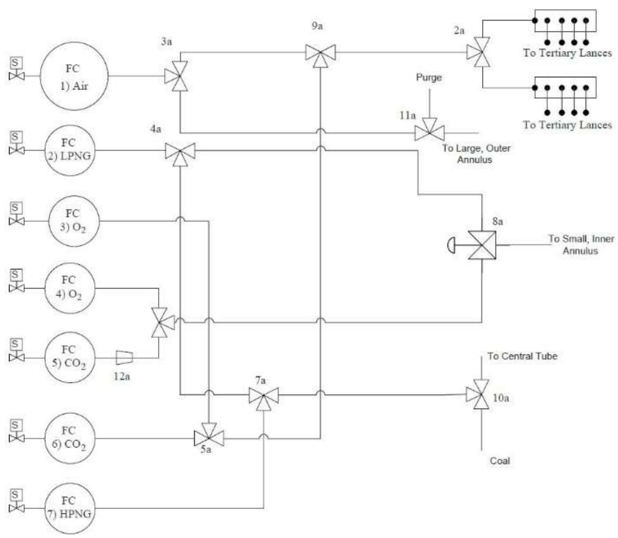
Simulations from Reaction Engineering International

	Case 1	Case 2	Case 3
CO_2/Coal Ratio	1.8:1	8.0:1	4.2:1
%O_2 Non-Coal Feed	20	20	10.4
Coal Vel. (m/s)	5.3	0.51	5.0
Inner O_2 Vel. (m/s)	1.03	0.5	5.2
Outer O_2 Vel. (m/s)	10.5	0.54	5.3

- Baseline Design
  - Coal conveyed with CO_2 in primary (~1:1)
  - Mixed O_2 and CO_2 in secondary annulus
  - Mixed O_2 and CO_2 in tertiary lances
  - CO_2 for temperature and momentum control

Burner Design

Connections From MFCs to Burner



Burner Installed

Burner Testing

PCHT Model

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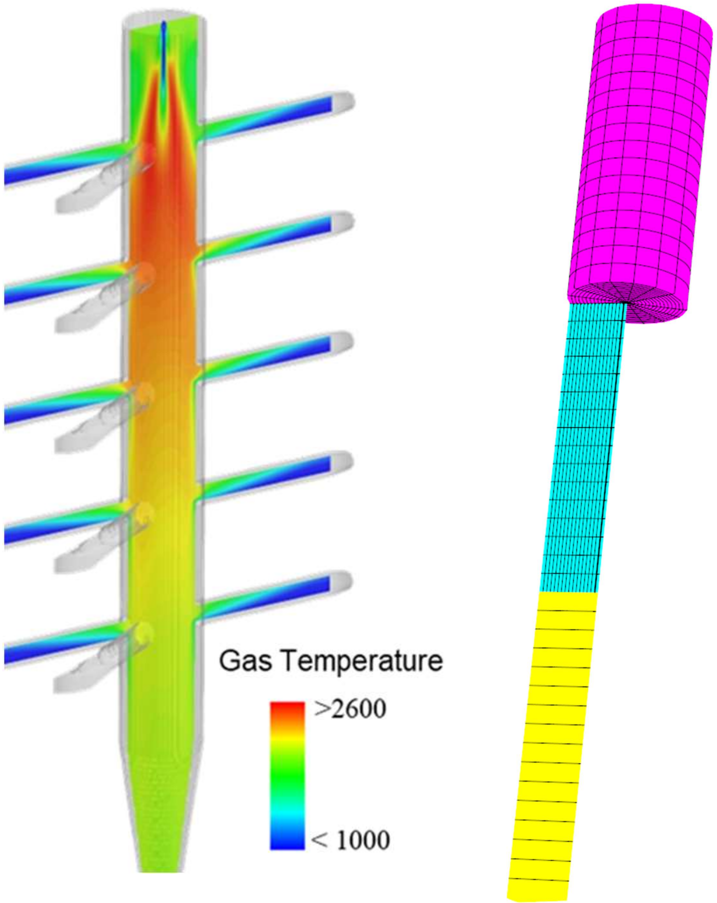
- Fast-running physics-based model
- Design screening, scale-up, plant integration
- Jet mixing, particle transport, reactions, radiative heat transfer
- Use adaptive dimensionality
  - Use 3D only where necessary
  - Biggest challenge is radiation
- Compare to reactor test data
- Model reactor scale-up, compare to CFD results



Calculation Speed-ups

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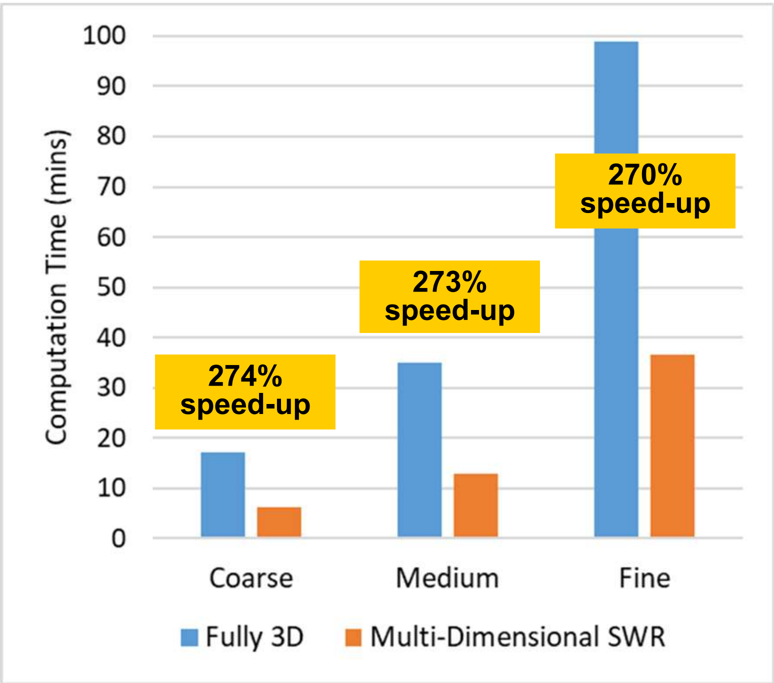
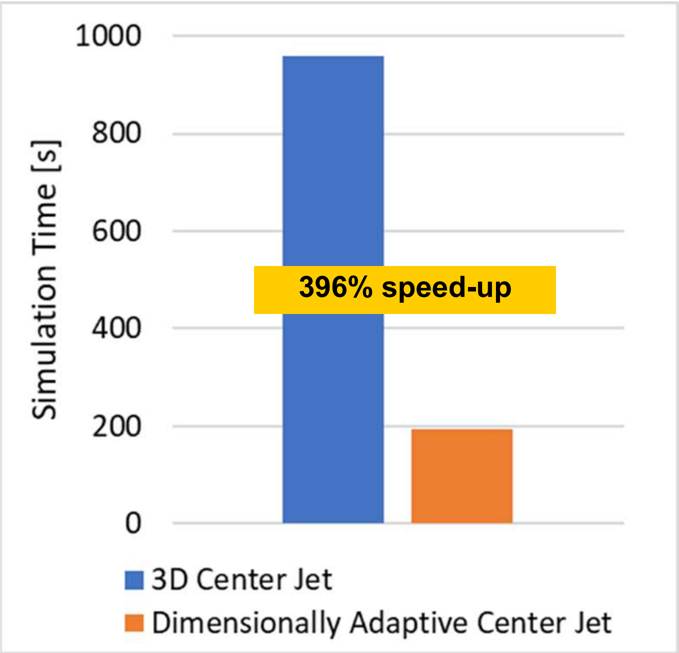
Moving from fully 3D to 3D/axi-symmetric/1D dimensionality reduces computational time with minimal loss in accuracy

Radiation Calculations



Median difference in incident wall flux < 1% for all meshes

Flow Calculations



Average difference in axial velocity < 3%

POC Reactor Design

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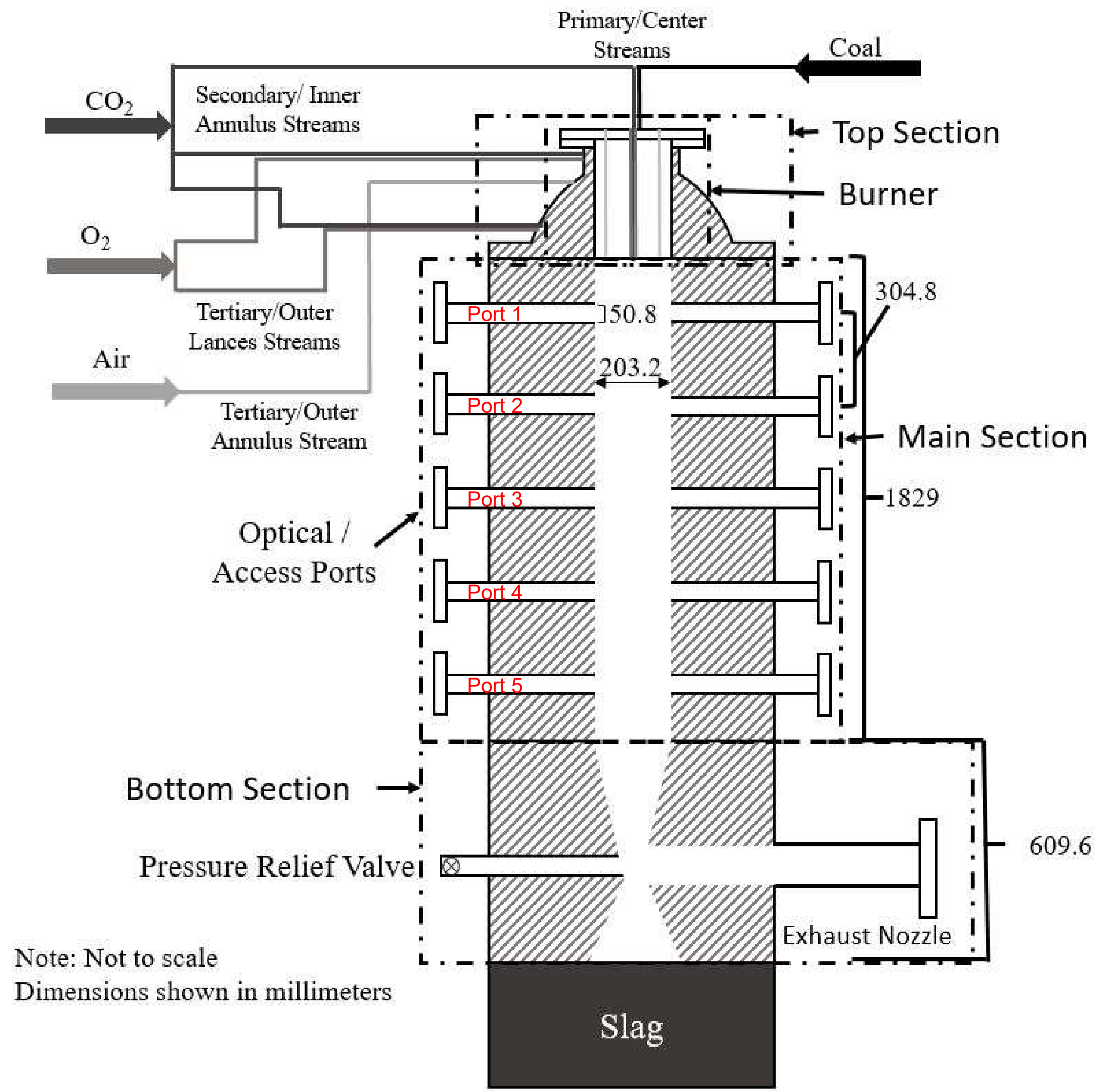
Four Refractory-Lined Sections

1) Top Section - Dome cap, houses Burner
2) Burner - Transports primary, secondary and tertiary flows into reactor
3) Main Section - 1.8 m combustion zone with optical access ports and embedded wall TC
4) Bottom Section - Slag collection and exhaust nozzle for flue gases

Total reactor weight ~ 6 tons



POC Reactor

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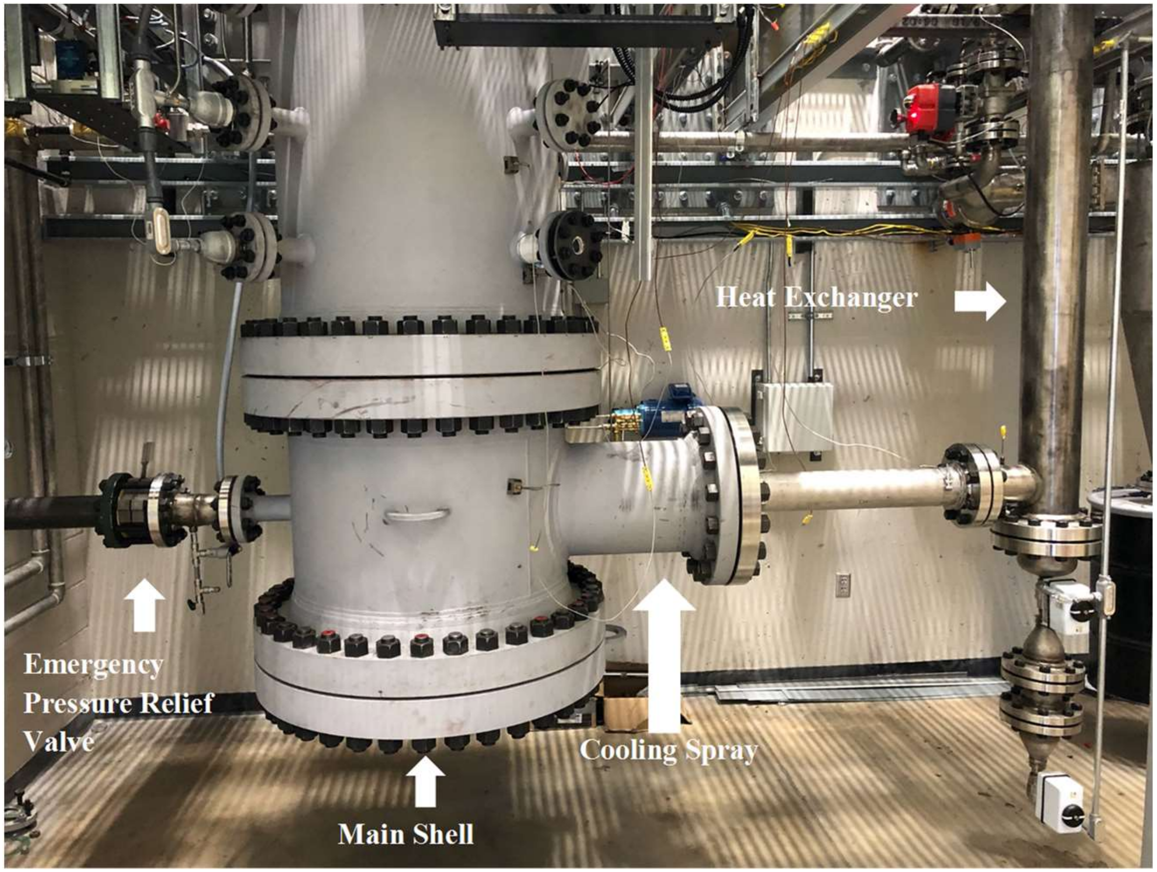

Reactor Optical Access

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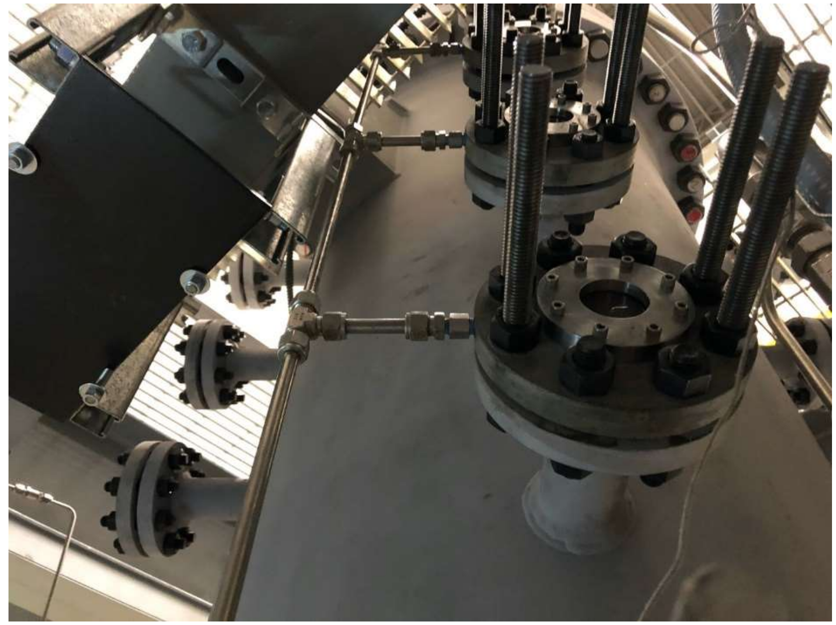
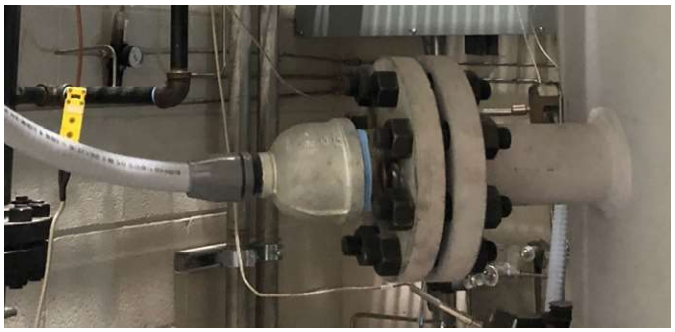


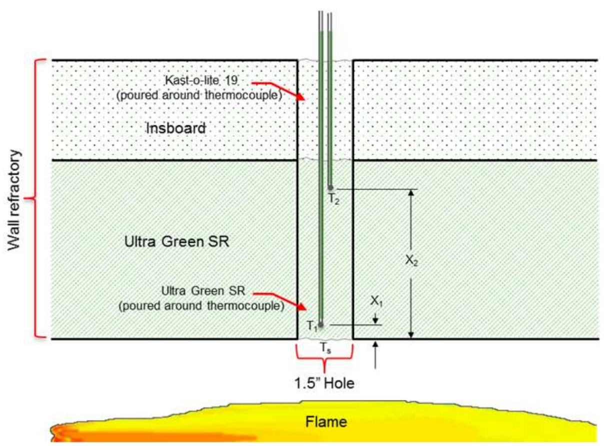
- Sapphire window assemblies have been machined and installed to allow optical measurements to be taken with reactor pressures at 20 bar
- These have been hydrostatic tested to 34 bar
- Integrated into assembly design
  - Purge system
  - Mounts for optical devices (radiometer, laser, passive FTIR)

Heat Flux

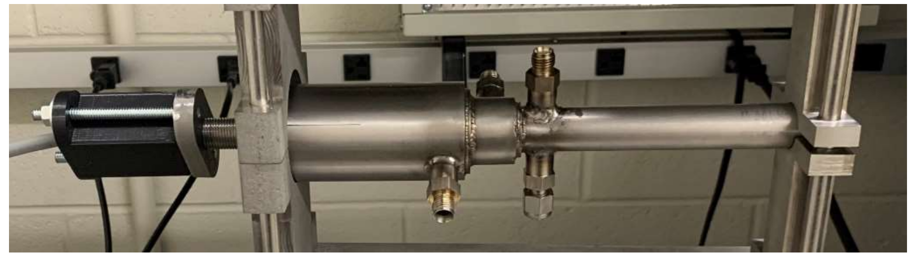
Multi-depth Thermocouples



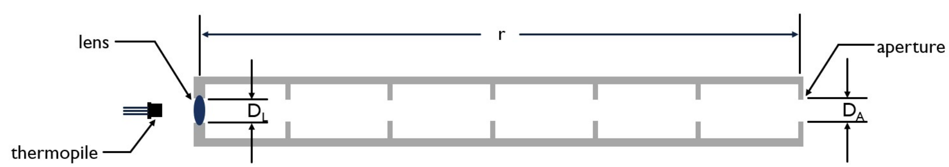
- Five Sets (along reactor axis) are installed and operating nominally
- Provide both inside refractory surface temperature and total heat flux
- System is ready for testing



Narrow Angle Radiometer (NAR)



- Prototype is completed along with extensive calibration and uncertainty analysis on a black body radiator
- 4 more devices are under construction
  - Electronics complete
  - Mechanical components expected next week
- One of these will be evaluated against Chalmers and University of Utah NARs (published results)



Assuming: surface or gas viewed through the aperture is diffuse and uniform in temperature and emissivity and Stefan-Boltzmann law applies

$$q_{A-L} = \omega_{L-A} A_A \cos\theta_A \, I_A \qquad \omega_{L-A} = \frac{A_L \cos\theta_L}{r^2} \qquad I_A = \frac{\epsilon_A \sigma}{\pi} T_A^4$$

for this configuration these reduce to: $q_{A-L} = \frac{A_L A_A}{r^2} \frac{\epsilon_A \sigma}{\pi} T_A^4$ which applies to both aperture and lens

Radiometer Calibrations

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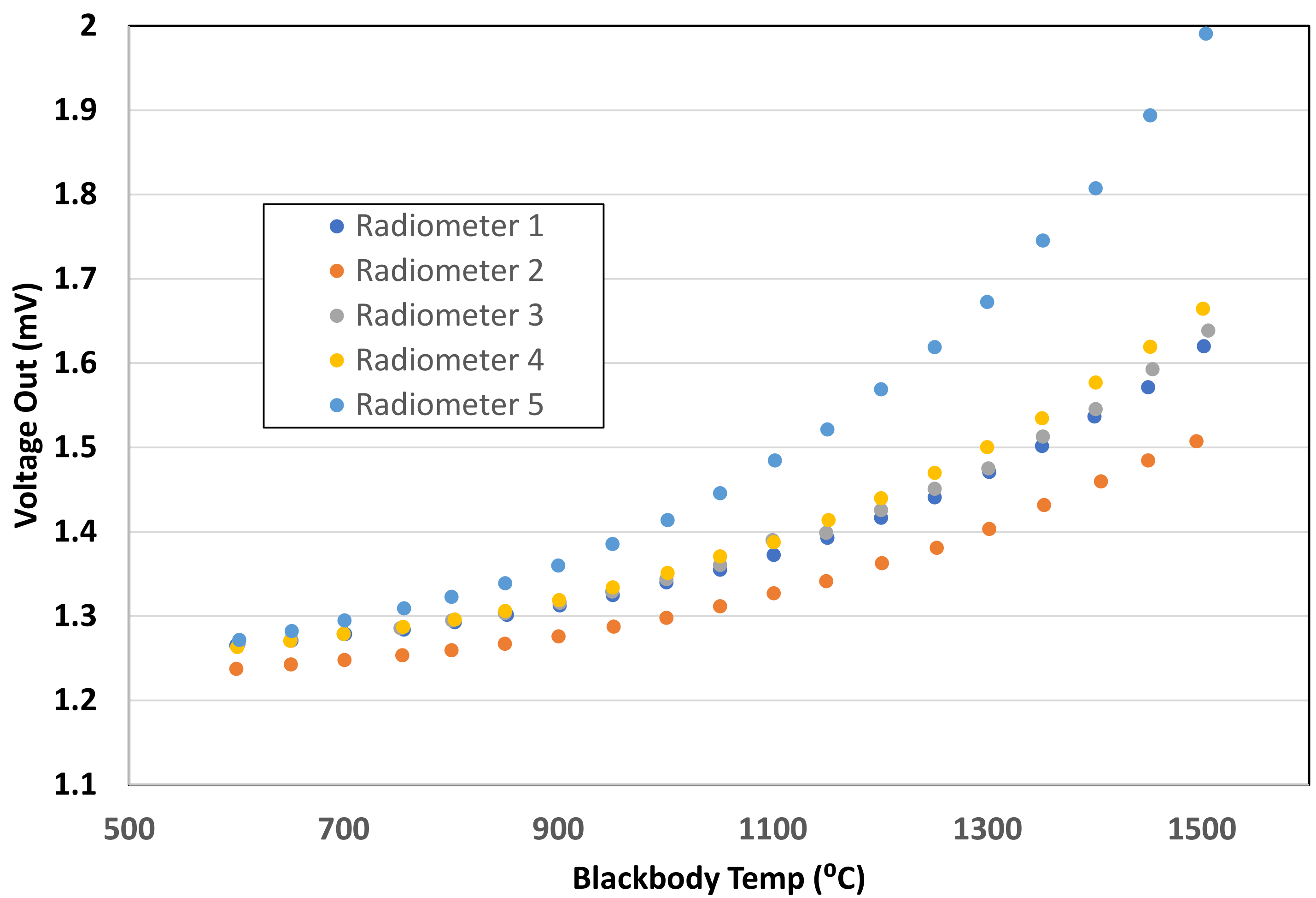

Temperature and Soot

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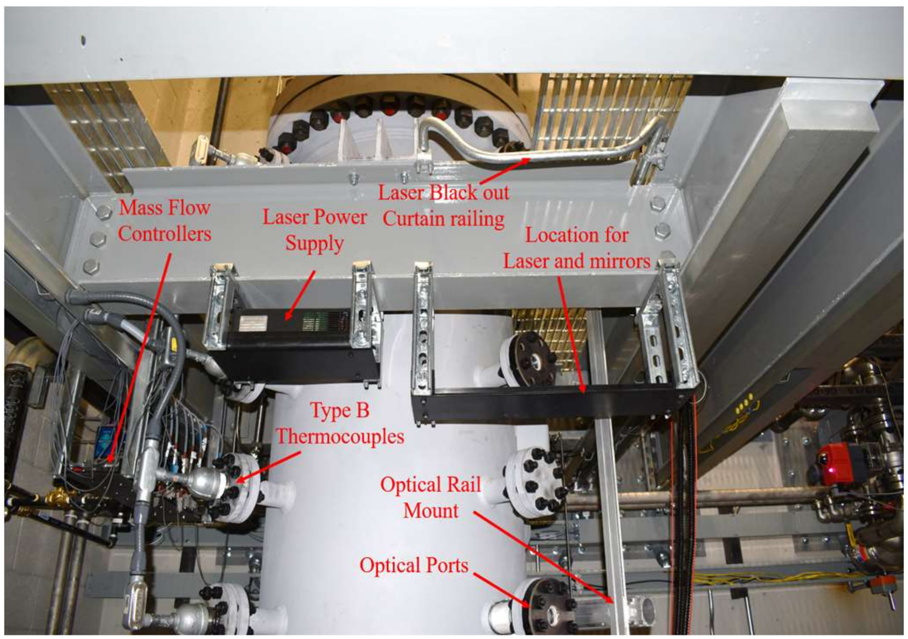
Two-color Laser Extinction (Soot and Ash)

- A table has been designed and fabricated to mount the laser on one side of the rector and integrating sphere on the opposite side of the reactor
- Curtain holders have been installed to protect users from stray laser light
- System is ready for testing – awaiting pressurized flame conditions



Optical Pyrometer / Passive FTIR

- A holder has been designed and installed for outside mounting of optical probe
- Purge system has been installed
- System is ready for testing

Control System

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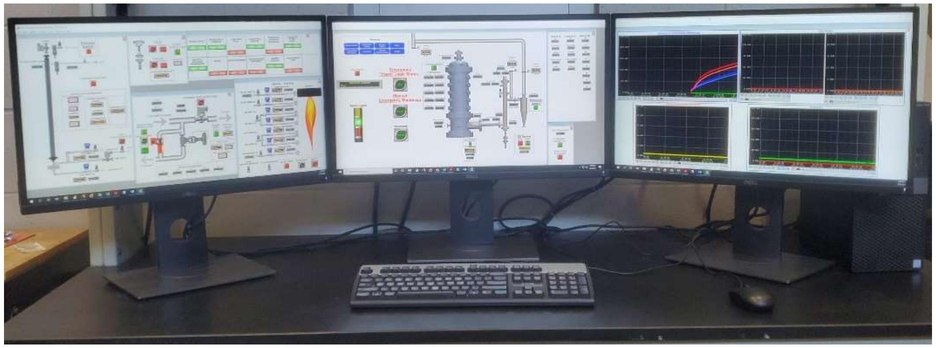

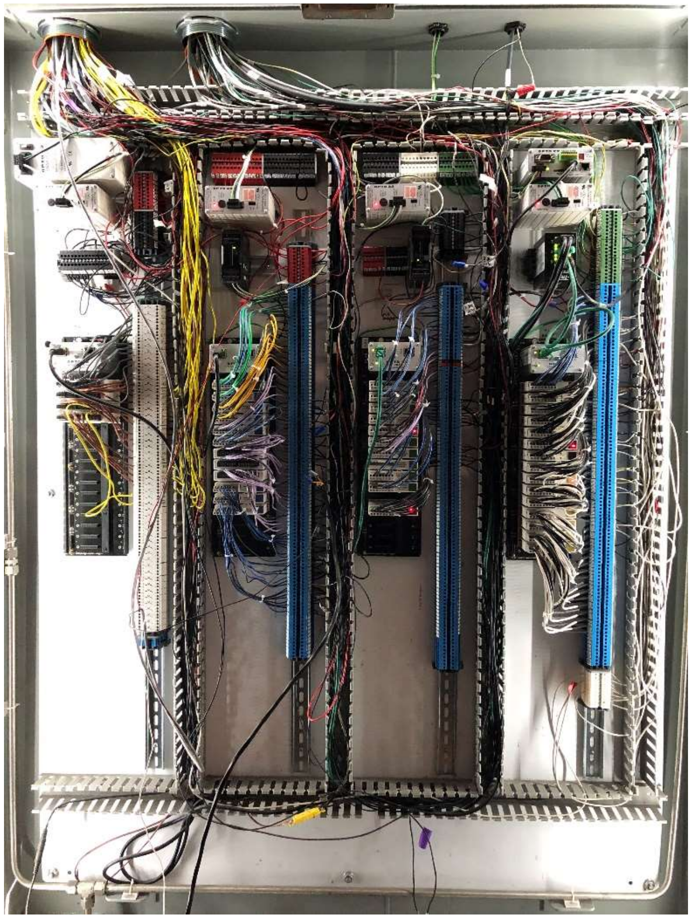

- OPTO 22 control
- 115 control points
- Integrated safety protocols
    - Interlocks
    - Logical decision points
- Historical data logs

Reactor Status

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- Completed:
  - Main reactor with diffusion burner system
    - Pressurized air, NG, O_2 and CO_2
  - Pressurized coal feed system
  - Flue gas cooling / clean-up system
  - Control system
  - HAZOP review and updates
  - Pressure burst test
  - Refractory cure
  - Shake down
  - Natural Gas Combustion
- Immediate Next Steps:
  - Pressurized coal combustion tests

Safety – HAZOP & Inspection

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- A Hazard and Operability Study was performed in June of 2019
- Participants in the study included:
  - College of Engineering Safety Personnel
  - College of Engineering Lab Managers
  - BYU Risk Management
  - Project Professors and Graduate Students
  - Invited Engineers from Industry with Similar Processes
- 76 Action Items were generated in this study that included:
  - Hardware Reconfigurations
  - Interlock Installation
  - Control Logic Modifications
  - Standard Operating Procedure Modifications
- All action items have been addressed and tested
- State Pressure Vessel Inspection has been passed and Operating Permit Obtained

Shakedown Test Results

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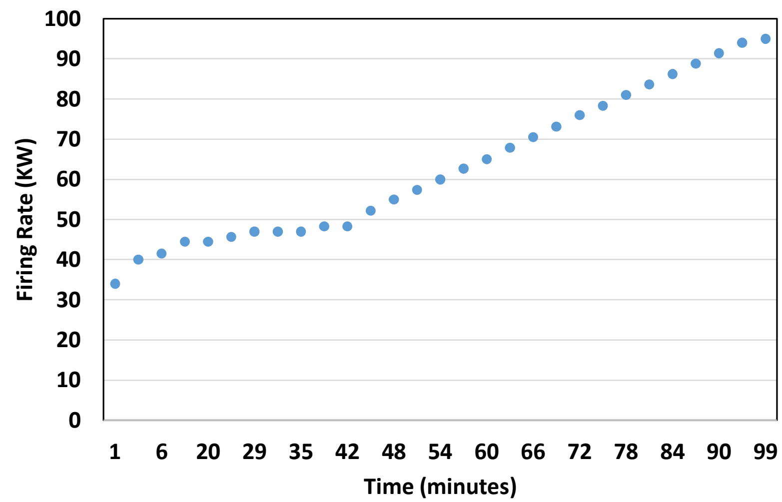
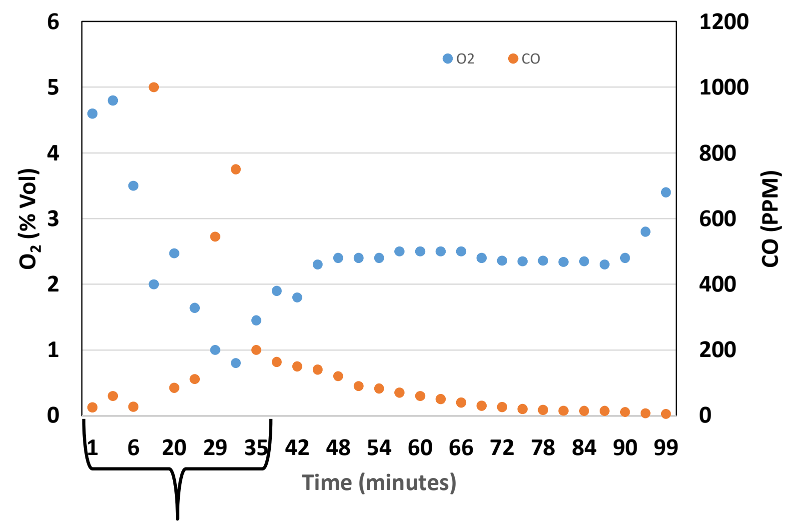
- The purpose of these tests is to verify that the equipment as installed was capable of:
  - Spanning the range of expected operating conditions
  - Stabilize a natural gas flame at atmospheric pressure
  - Identify any problems with equipment configuration

- Data presented on this slide are concerned with firing rate and flame stability

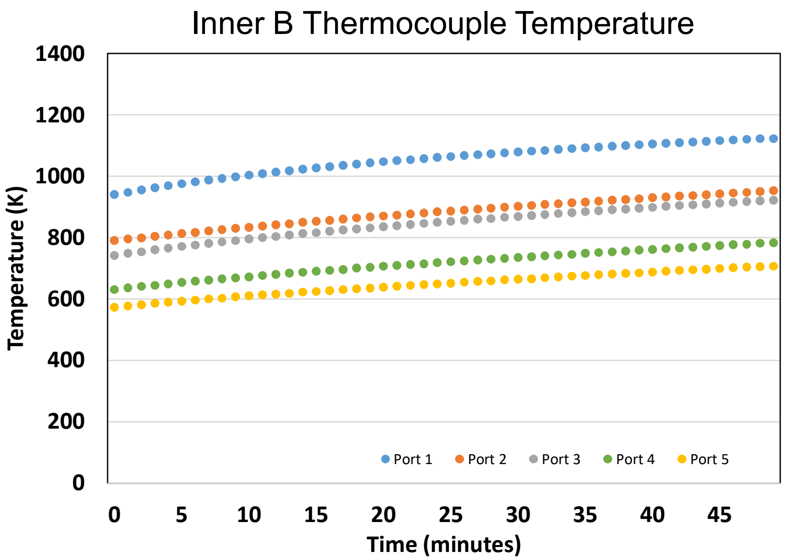
- Data presented on the next slide demonstrate the functionality of the multi-depth thermocouples

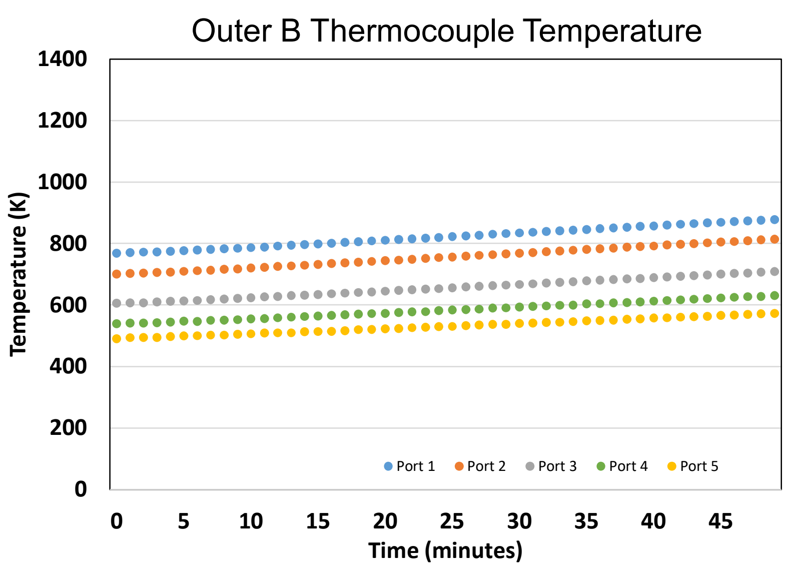


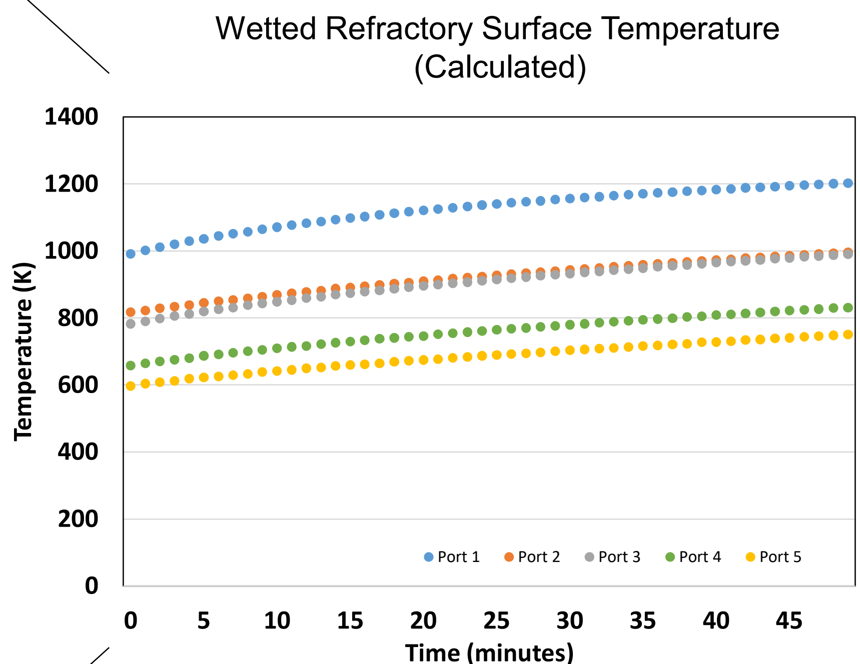


Equivalence ratio near 1/ analyzer

Shakedown Test Results







Targeted Operating Conditions

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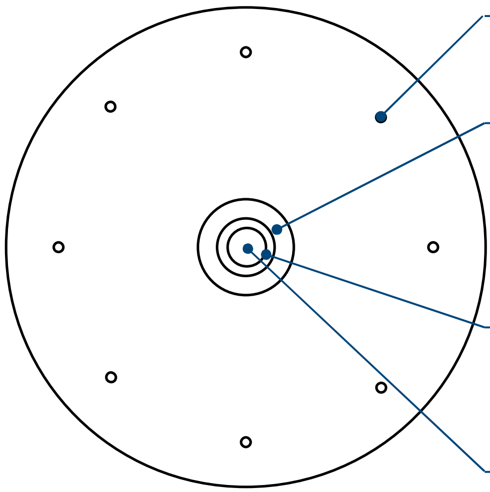
Burner Configuration



Similar to Case 3
From CFD Modeling

Geometry and Firing Conditions

Label	Port or Anulus	ID (mm)	OD (mm)	Coal (kg/h)	CO_2 (kg/h)	O_2 (kg/h)
A	O_2 ports	3.8608	NA	0	37.2	0
B	O_2 & CO_2 anulus	28.448	31.75	0	55	27
C	natural gas anulus	8.509	9.525	NA	NA	NA
D	Coal & CO_2 port	NA	6.35	13.6	0	0

Pressurized Coal Combustion

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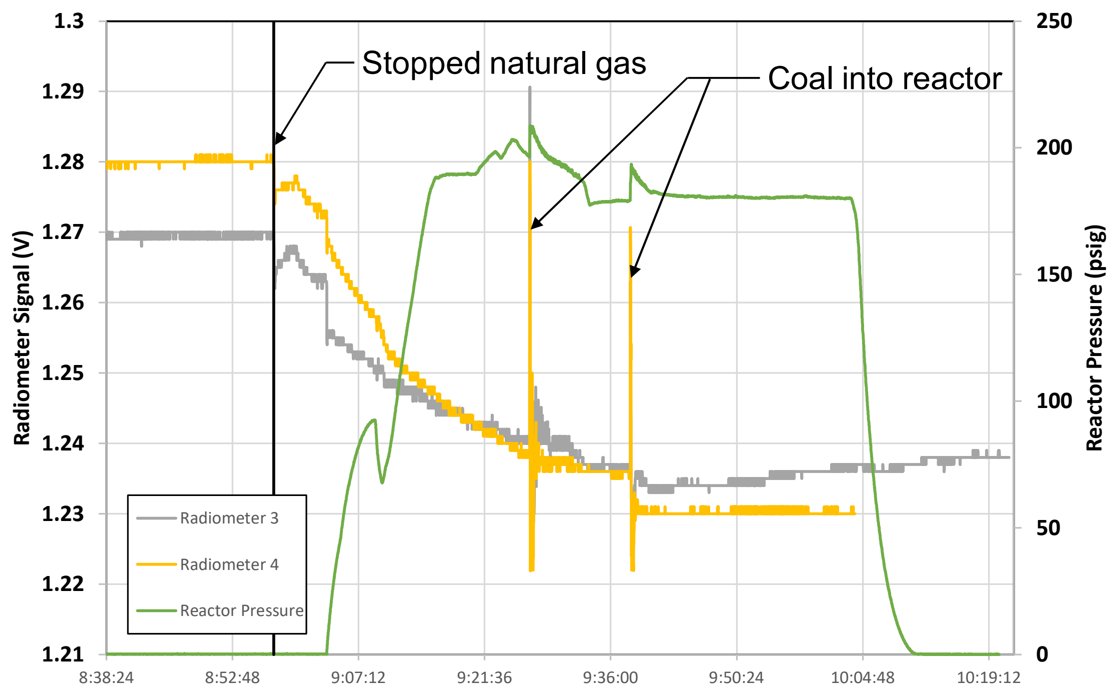
Attempt #1



- All systems functioned nominally
- Coal was only introduced into reactor in two plugs
- Postmortem analysis indicated that students used coal that had sat in a drum over a high humidity weekend (It was agglomerated)
- Next attempt will occur during the week of May 10th.

Milestones

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Year 1 - Milestone and Related Task	Scheduled Completion	Actual Completion	Percent Completed
Update Project Management Plan (Task 1.1)	12/31/16	12/6/16	100%
DOE-NETL Kickoff Meeting (Task 1.2)	3/31/17	01/27/17	100%
Diffusion Flame Burner Design (Task 4.1)	9/30/17	9/30/17	100%

Year 2/3 - Milestone and Related Task	Scheduled Completion	Actual Completion	Percent Completed
Reactor Component Construction (Task 2.0)	6/30/18	7/15/18	100%
Coal Feed System Construction (Task 3.2)	12/31/19*	6/30/20	100%
Reactor Assembly and Acceptance (Task 5.1)	12/31/19*	8/31/20	100%

Year 4/5 - Milestone and Related Task	Scheduled Completion	Actual Completion	Percent Completed
Diffusion Flame Tests (5.2)	6/30/21*		20%
Flameless Combustion Test (5.3)	9/30/21*		0%
Reactor Test Data Modeling (6.2)	9/30/21*		0%

* Adjusted schedule after project extension

Acknowledgment/Disclaimer

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