B&W

power generation group

Development of Fireside Corrosion Models for Advanced Combustion Systems

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State of Knowledge

Major Fireside Corrosion Mechanisms in Coal-Fired Boilers:

- **Furnace Walls**
  - Sulfidation (high-S coal, low-NOx & staged combustion)
  - Chlorination (high-Cl coal, low-NOx & staged combustion)
  - Corrosion fatigue cracking (large ΔT, large ΔCTE, high-Cl, high-S)
  - Oxidation

- **Superheaters/Reheaters**
  - Coal ash (hot) corrosion (high-S coal, liquid phase)
  - Sulfidation (high-S coal, internal attack)
  - Chlorination (high-Cl coal, liquid phase)
  - Carburization (high LOI, staged combustion)
  - Oxidation

State of Knowledge (cont.)

- Basic corrosion mechanisms reasonably understood
- Predictive equations available for furnace walls linking corrosion rate to T, Cr%, and [H_2S]
- Mechanism for extremely high furnace-wall wastage under staged combustion Identified
- Reliable, scientific prediction for coal ash corrosion on SH/RH is lacking
- No direct link of corrosion rate to coal chemistry!

Program Objectives

- Determine the effects of coal impurities on fireside corrosion
- Generate fireside corrosion database from long-term laboratory testing simulating modern coal-fired boiler conditions
- Develop corrosion models with predictive equations for lower furnace walls and superheaters

Program Approach

- Select eight US coals (from 24 candidates) containing a wide range of impurity concentrations
- Burn coals in a pilot-scale combustion facility to produce fireside conditions of interest
- Perform in-furnace gas and deposit sampling at furnace wall and superheater locations
- Generate long-term corrosion data of alloys and coatings from laboratory fireside exposures
- Correlate corrosion rates with coal impurities and formulate predictive equations for furnace wall and SH/RH corrosion

Program Major Tasks

- **Task 1** – Coal Selection, Procurement, and Handling
- **Task 2** –Pilot Scale Combustion Testing
- **Task 3** – In-Furnace Gas and Deposit Sampling
- **Task 4** – Laboratory Corrosion Testing
- **Task 5** – Corrosion Model Development
- **Task 6** – Management and Reporting

Task 1 - Coal Selection, Procurement, and Handling

Approach

- Review coal databases and update commercial availability - Done
- Select 24 common U.S. coals (bituminous, subbituminous, PRB, and lignite) - Done
- Obtain coal samples and perform coal analysis for impurities if necessary – Done
- Down-select 8 coals for pilot-scale combustion testing - Done
- Procure, handle, pulverize, and store coals – Ongoing

Task 1 - Coal Selection, Procurement, and Handling

Final Coal Selection

Group	Coal Company	ASTM Rank	State	County	Mine	Seam	Sulfur, % A.R.	Chlorine, % dry	Ash % dry	BAR‡	Comments*	2006 Annual Production, M short tons
1	American Coal Co.	hvBb	IL	Saline	Galatia	#6 Seam Washed	2.7	0.39	9.1	0.39	Med S, High Cl	7.20
2	Buckeye Industrial Mining Co.	hvAb	PA	Butler	-	Mahoning #7	1.6	0.14	7.7	0.45	Med S, Med Cl	0.12
3	Thunder Basin Coal Co. LLC	subB	WY	Campbell	Black Thunder	Wyodak	0.3	0.0012	6.8	0.64	Low S, Low Cl	92.60
4	Dakota Westmoreland Corp.	lig	ND	Mercer	Freedom	Beulah	0.7	0.0010	11.9	0.84	High OS, High BAR,	15.20
5	Gatling Coal Co.	hvBb	OH	Meigs	Gatling	-	2.0	0.09	10.4	0.41	Med S,	
	AEP/Mountaineer										Low to Med Cl	
6	Black Beauty Coal Co.	hvCb	IN	Gibson	-	Indiana #6	1.1	0.20	8.1	0.53	Med to High S,	3.10
7	The Ohio Valley Coal Co.	hvBb	OH	Belmont	Pohawtan No. 6	Pittsburgh #8	4.3	0.05	9.1	0.58	High S, Low Cl	4.30
	Murray Energy											
8	Murray Energy	hvBb	KY	Union	-	Kentucky #9	2.4	0.01	9.2	0.81	High S, Equal PS	3.70
											and OS, Low Cl	

*** USGS criteria for ranking sulfur in coal reported wt.% on an as-received basis: low < 1%, medium 1 to 3%, high > 3%.**
***PS = Pyritic Sulfur**
***OS = Organic Sulfur**
‡BAR = Base/Acid

Task 1 - Coal Selection, Procurement, and Handling

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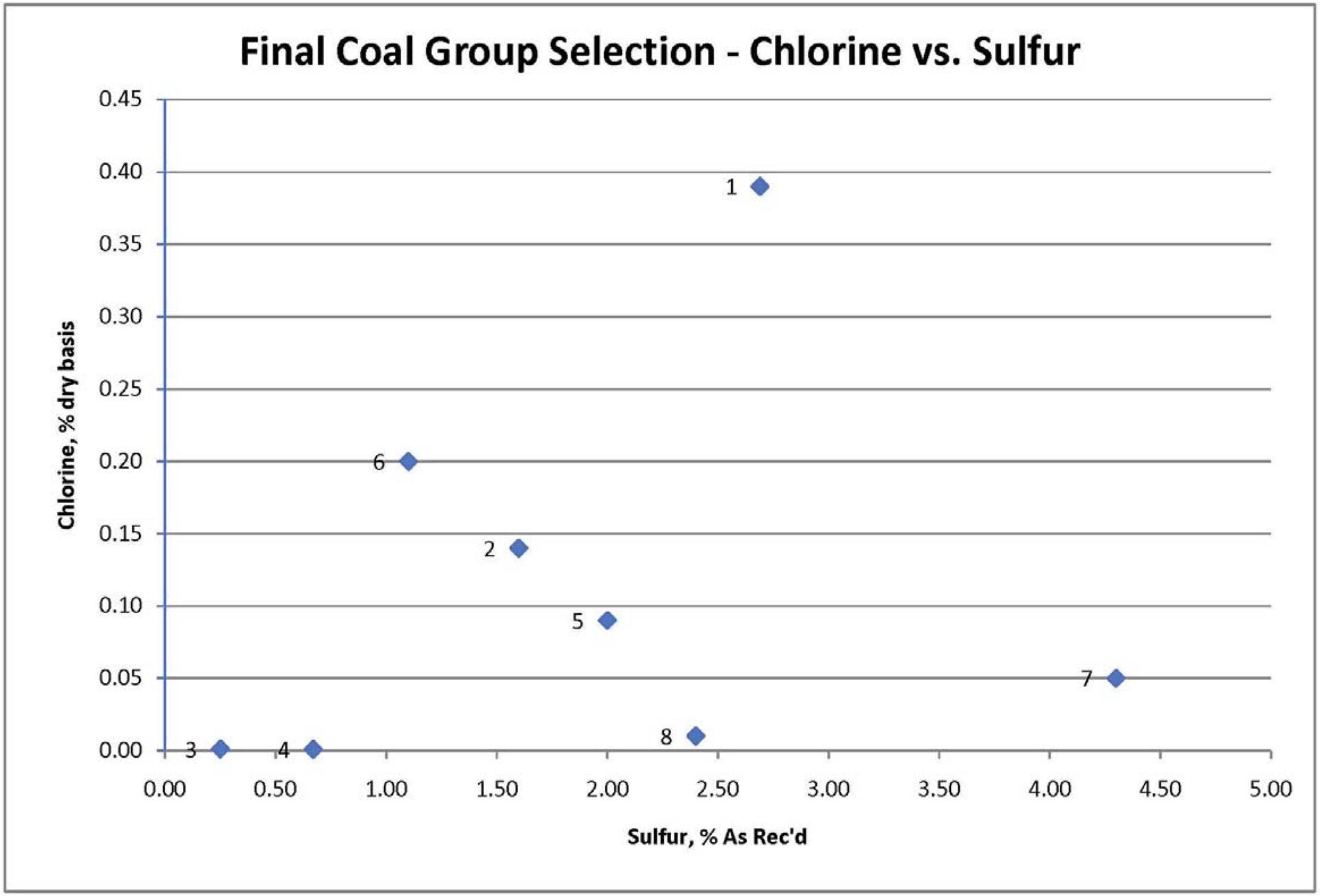


Task 1 - Coal Selection, Procurement, and Handling

Status of Task 1:

- **Three Coals Processed and Delivered**
  - PRB
  - Lignite
  - IL #6 Galatia
  - Coal Analyses Done
- **Balance of Coals Being Secured**

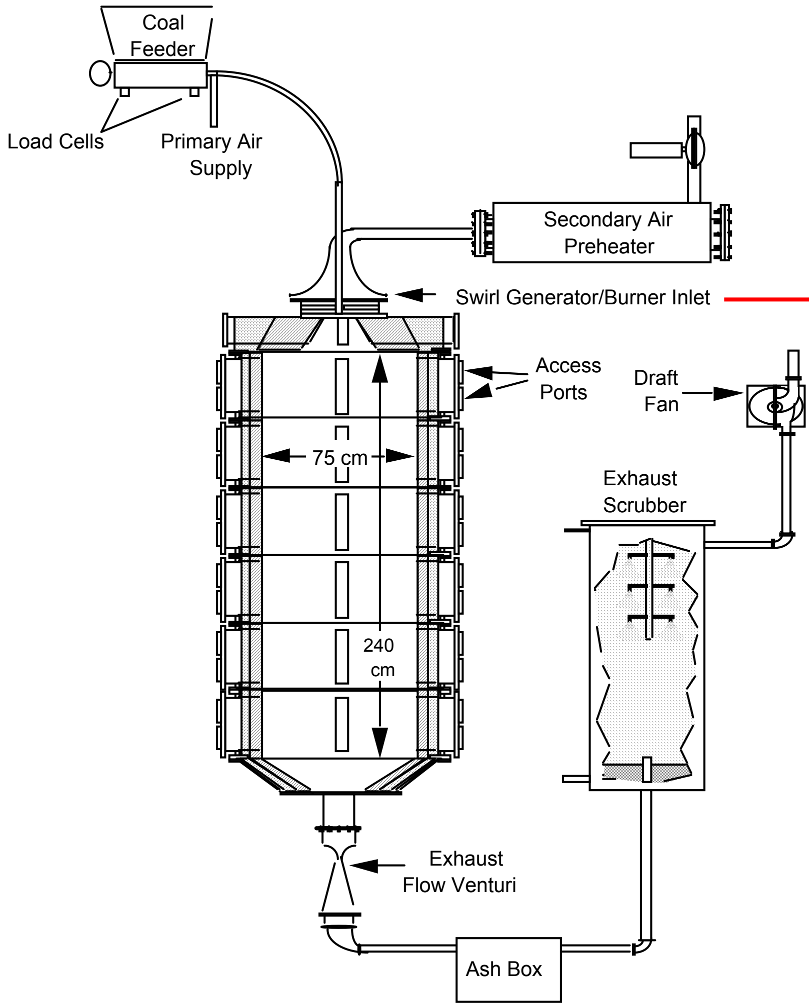
Task 2 – Pilot Scale Combustion Testing

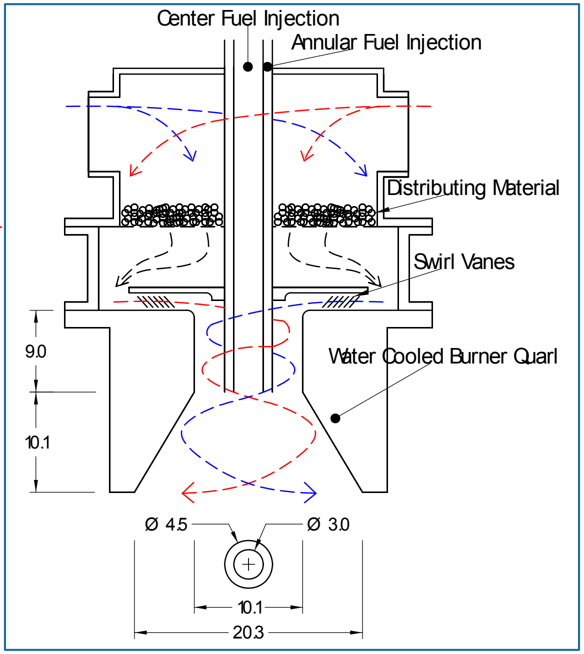
Approach:

- Combustion tests of eight coals using BYU pilot-scale combustion facility (Burner Flow Reactor - BFR)
- Staged combustion @0.85
- B&W CFD modeling support to optimize combustion conditions
- Air split similar to utility boilers
- Gas and deposit probing and analyses

Task 2 – Pilot Scale Combustion Testing

Burner Flow Reactor (BFR) – 0.6 MBtu/hr heat input

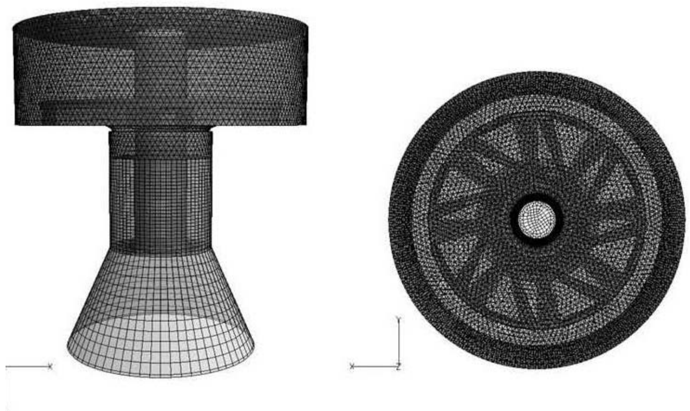


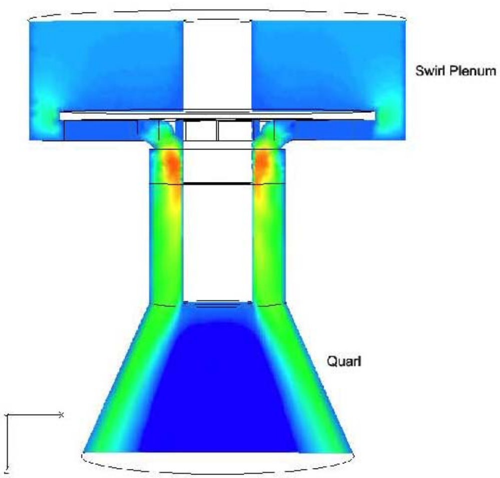


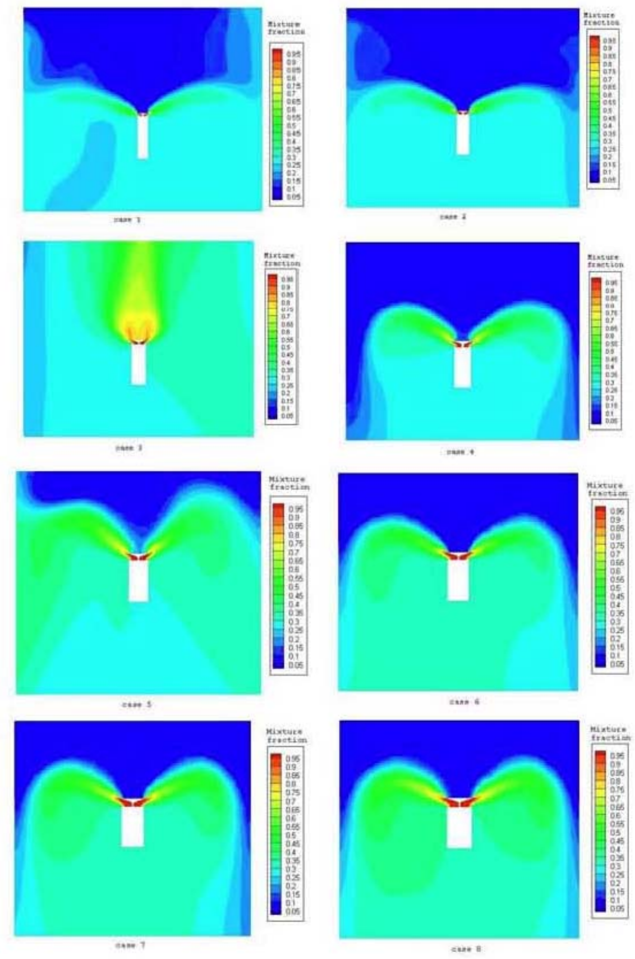
Variable Swirl Burner

Task 2 – Pilot Scale Combustion Testing

CFD Performed by B&W to Support BFR Mod.







Task 2 – Pilot Scale Combustion Testing

- BFR site preparation near completion
  - ~15 short test burns performed
    - 1 to 5 hours of steady state operation each
    - Test coals: Utah bituminous, IL #6 Galatia, and PRB
    - Reducing burner zone and oxidizing burnout zone established
  - A 30-hour PRB combustion run demonstrated
    - Around the clock operation
    - No major problems encountered (except for the coal feed system that is to be replaced)
    - Reducing burner zone and oxidizing burnout zone maintained throughout
- A new coal feed system installed after the 30-hour PRB run
    - Provides stable coal feed rate for a longer period of operation
    - The 30-hour PRB test to be repeated

Task 2 – Pilot Scale Combustion Testing

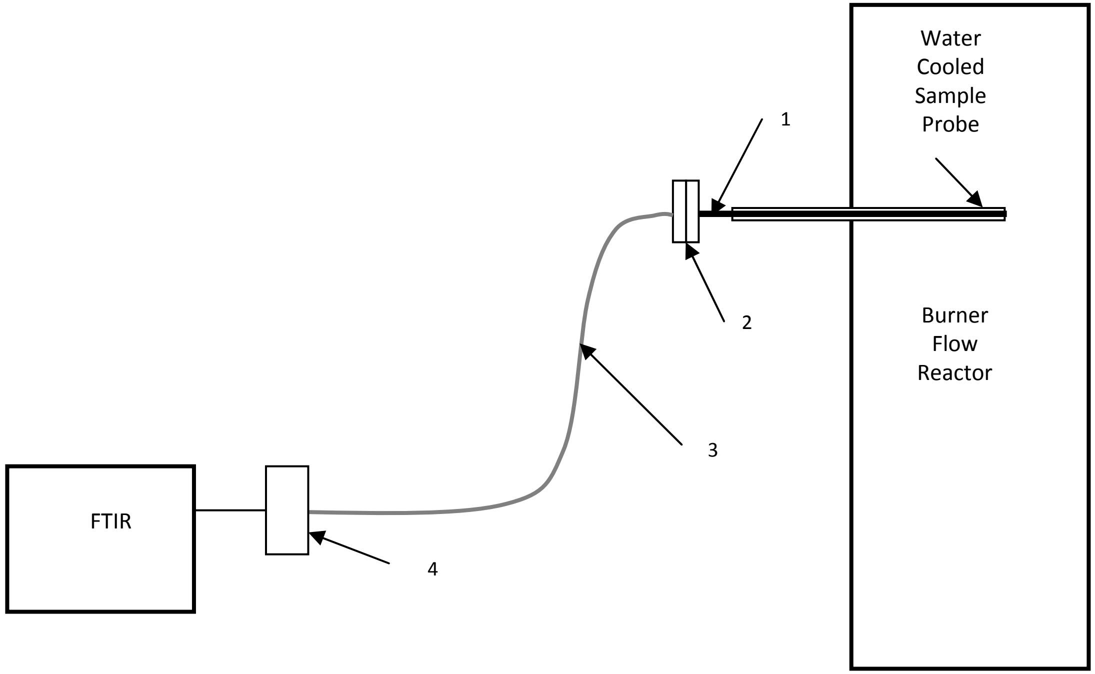
New Coal Feed System for BFR

Task 3 – Gas and Deposit Sampling

Approach

- Determine corrosive environments adjacent to
  - Furnace Wall – sulfurizing/reducing
  - SH/RH – sulfurizing/oxidizing
- Perform gas and deposit sampling at burner and burnout zones
  - Flue gases
  - Deposits
- Analyze gas and deposit samples
  - In-situ gases analysis
  - Deposits collected online and analyzed offline

Task 3 – Gas and Deposit Sampling



1: 2-m heated sample probe.

2: heated filter

3: 7.6-m heated Teflon sample line

4: heated pump

Task 3 – Gas and Deposit Sampling

Gas Sampling

- Advanced gas analytical system to be employed
  - GC
  - FTIR
  - Horiba multi-gas analyzer

- Gas species
  - CO_2 SO_2 SO_3 NO_x H_2O O_2
    CO H_2S HCl H_2

- Air and water-cooled probes + heated sampling lines
  - Stainless steel construction
  - Maintained at 180^{o}C
  - Particulate filter

- GC was received after the 30-hour PRB run
  - To be used in the PRB repeat test

Task 3 – Gas and Deposit Sampling

Gas Compositions Measured in the Burner Zone During the 30-Hour PRB Run

Radial Position (cm)	CO ppm	CO_2 %	H_2O %	H_2S ppm	HCl ppm	SO_3 ppm	SO_2 ppm	NO ppm	O_2 %	H_2 ppm
0	44.59	10.48	7.11	11.85	0.06	-32.97	73.36	337.09	11.65	N/A
10	9951.34	14.20	10.51	92.87	-0.36	-85.07	198.54	315.95	4.53	N/A
20	18063.60	13.63	10.66	252.08	-0.60	-91.85	394.16	206.99	3.48	N/A
30	24102.20	11.30	17.31	821.65	-0.51	-189.37	76.03	129.52	2.78	N/A
40	36956.30	11.25	15.11	697.66	-0.10	-148.11	72.87	94.27	2.45	N/A
50	31858.61	11.23	11.74	438.93	0.38	-5.23	25.02	77.12	2.33	N/A
60	11946.36	11.49	11.33	99.15	0.32	-19.83	68.50	160.72	2.39	N/A
70	17786.34	11.28	11.55	73.17	0.17	-38.16	72.81	142.88	2.62	N/A

Task 3 – Gas and Deposit Sampling

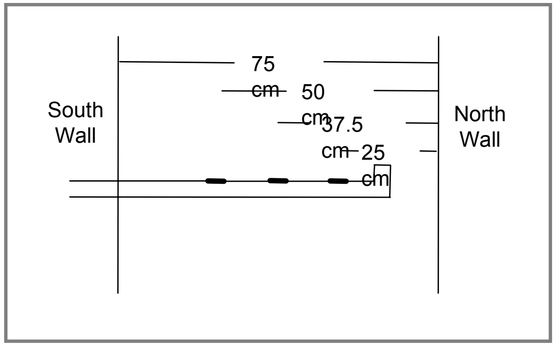
Gas Compositions Measured in the Burnout Zone During the 30-Hour PRB Run

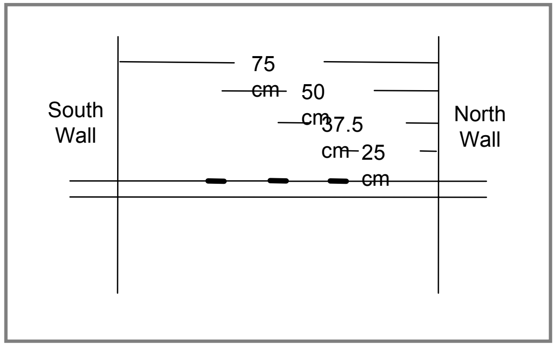
Radial Position (cm)	CO ppm	CO_2 %	H_2O %	H_2S ppm	HCl ppm	SO_3 ppm	SO_2 ppm	NO ppm	O_2 %	H_2 ppm
0	1837.18	14.77	10.32	74.19	1.52	-39.54	339.44	130.27	3.99	N/A
10	2331.37	14.29	9.68	83.74	1.17	-10.18	259.86	137.99	2.80	N/A
20	3150.84	14.45	9.79	44.12	1.29	-0.430	242.85	127.17	2.50	N/A
30	2497.18	14.09	9.68	53.33	1.08	1.2694	256.67	117.00	2.34	N/A
40	1702.95	13.81	9.79	51.98	1.05	-17.90	260.17	117.41	2.34	N/A
50	2488.23	13.89	9.91	65.98	1.06	-3.623	244.52	115.13	2.4	N/A
60	258.32	13.45	9.64	20.79	0.81	-25.30	245.40	140.48	2.36	N/A
70	2078.91	13.67	9.99	32.56	0.99	-33.40	242.68	116.61	2.38	N/A

Task 3 – Gas and Deposit Sampling

Deposit Sampling

- Deposition probes with removable SS sleeves
- Water-cooled probe controlled at 800-1000ºF in burner zone
- Air-cooled probe controlled at 1100-1500ºF in the burnout zone





Task 4 – Laboratory Corrosion Testing

Approach

- Simulate furnace wall and SH conditions in laboratory
- Conditions based on Task 3 results
- Incorporate coal impurities into testing
- Long-term exposure to generate reliable corrosion database
- Evaluate performance of a wide range of alloy and coating compositions

Task 4 – Laboratory Corrosion Testing

- Two furnace systems running lower furnace and SH conditions in parallel
- Each test runs for 1000 hours
- A total of 11 boiler-tube alloys and weld overlays exposed in each test
- Duplicate samples for each material
  - Measure weight/thickness changes
  - X-sections
  - Optical and SEM/EDS examinations
- Investigate effect of metal temperatures on fireside corrosion
  - Furnace wall: 750°F, 850°F, 950°F
  - SH: 1200°F, 1300°F, 1400°F

Task 5 – Corrosion Model Development

Approach

- Evaluate corrosion database generated from Task 4
- Develop corrosion models
  - Sulfidation on furnace walls
  - Coal ash (hot) corrosion on superheaters snd reheaters
- Formulate predictive equations
  - Correlate corrosion with coal chemistry
  - Consider thermodynamics and kinetics
  - Apply scientific and engineering principles
  - Avoid empirical correlation
  - Professor R. A. Rapp serves as consultant
- Incorporate prior B&W corrosion data, if applicable

Summary

- **Task 1 –**
  - Eight coals selected
  - Three Coals procured, pulverized, and delivered to test site
    - PRB
    - Lignite
    - IL #6 Galatia
  - Coal analyses done
  - Balance of coal sources being secured
- **Tasks 2 and 3** –
  - BFR site prep near completion
  - 15 short test runs performed to date
  - 30-hour PRB coal tested
  - New coal feed system installed
  - GC added to gas sampling system
  - PRB test to be repeated
  - SO_3 and HCl measurements with FTIR still need refinement
- **Task 4 –**
  - B&W laboratory testing facilities ready
  - Testing delayed (waiting for the repeat PRB run)

Acknowledgement

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