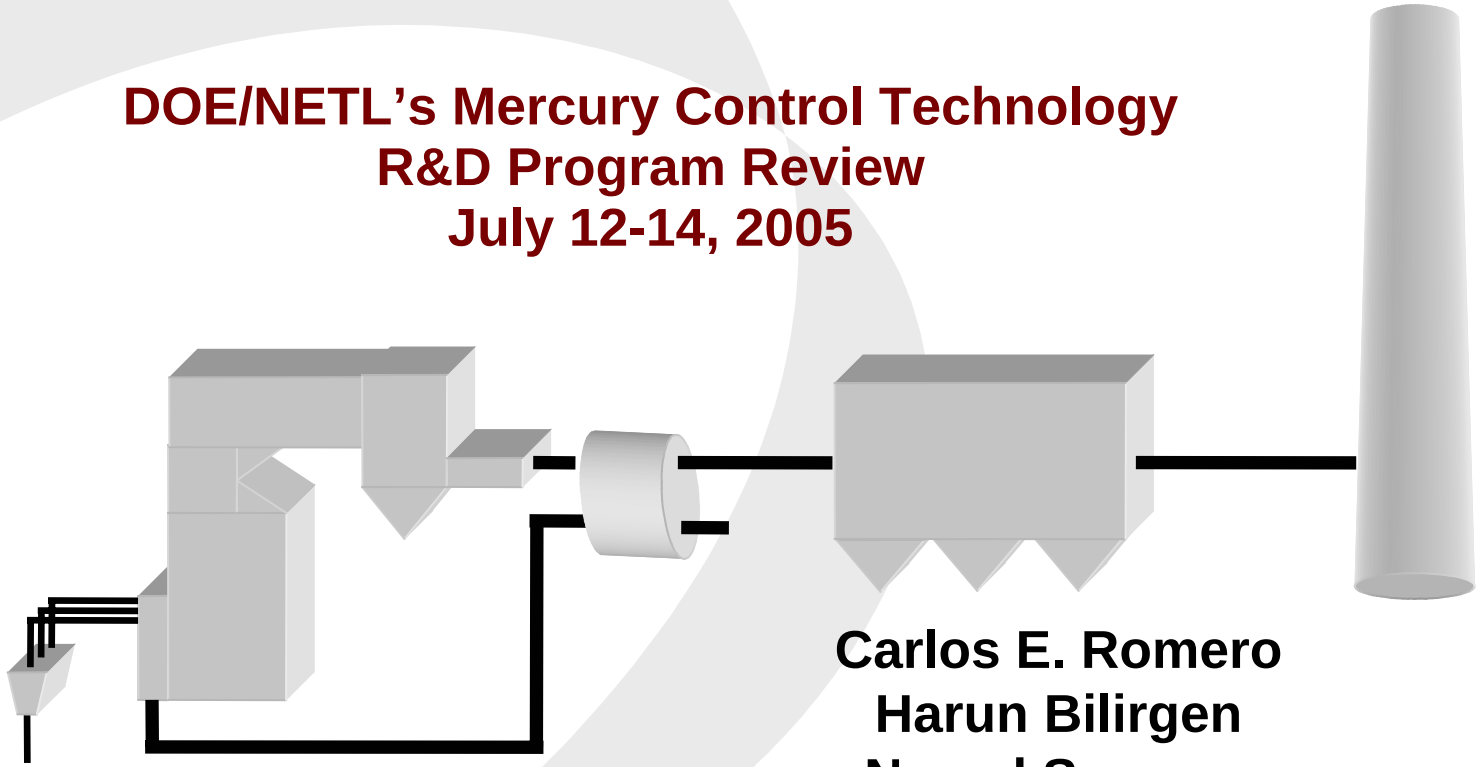
Impact of Modified Boiler Control Settings on Mercury Emissions

DOE/NETL's Mercury Control Technology R&D Program Review
July 12-14, 2005



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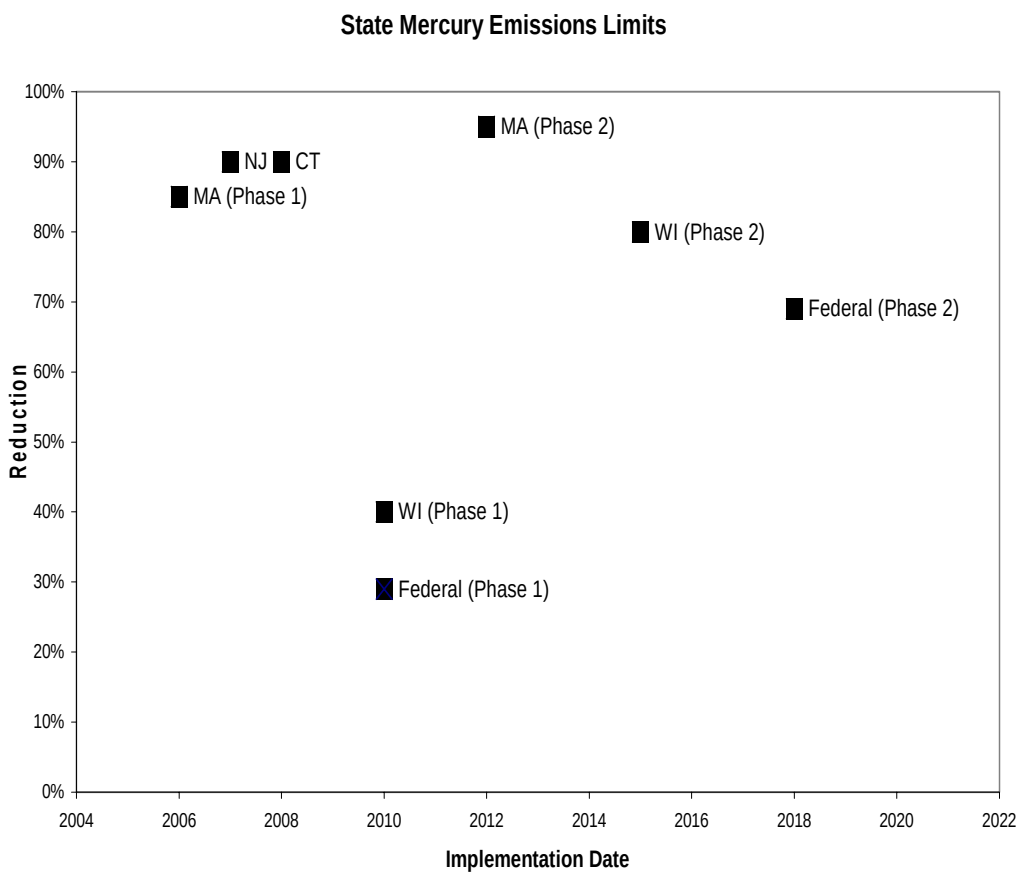
BACKGROUND

Approximately 75 tons of mercury are found in the coal delivered to coal-fired power plants each year and about two thirds of this mercury is emitted to the air, resulting in about 50 tons being emitted annually. This 25-ton reduction is achieved in the power plant boilers and through existing pollution controls such as FFs and ESPs for particulate matter, scrubbers for SO_2 and Selective Catalytic Reduction (SCR) systems for NO_x Emissions[1].



[1] Controlling Power Plant Emissions: Overview, USEPA Web Site.

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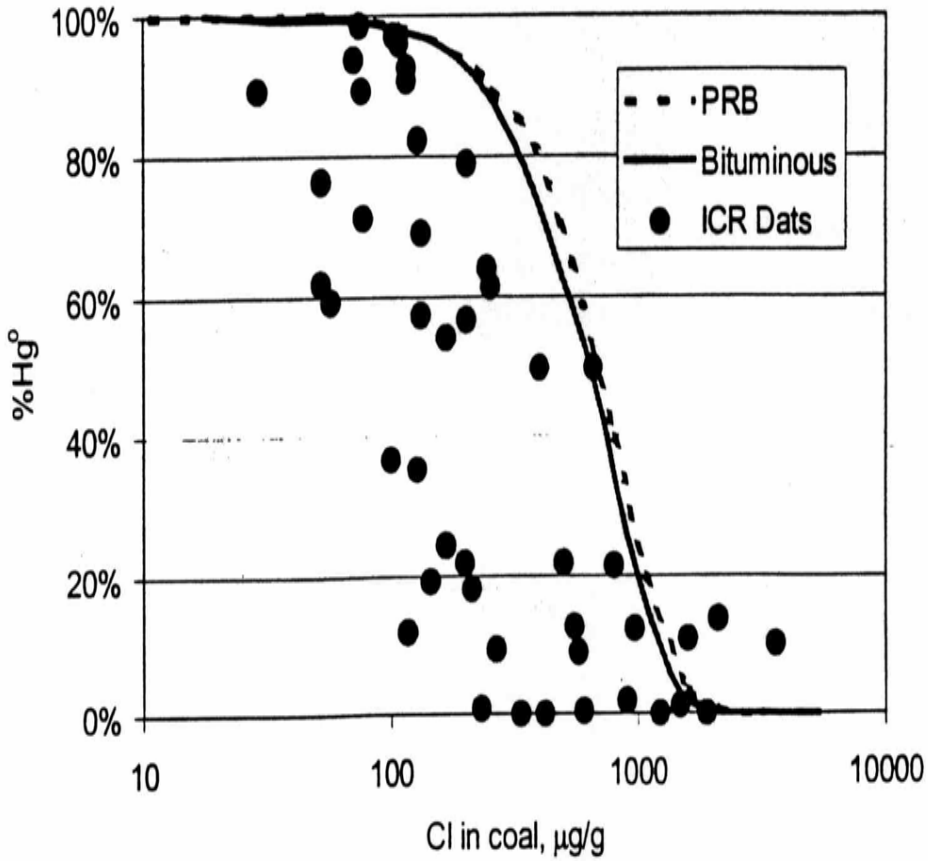
MERCURY EMISSIONS FROM COAL-FIRED BOILERS

- Concentration of Hg^0 from coal-fired boilers varies from 10 to >90%. It depends on:
  - Coal Blend Characteristics
  - Boiler Design/Equipment
  - **Boiler Operating Conditions!!**
- Coal blend effect on Hg emissions is related to the Cl concentration in the coal and to some extent to other elements such as S, Fe and Ca.



After Senior, C., et.al. "Modeling Gaseous Hg Behavior In Practical Combustion Systems."

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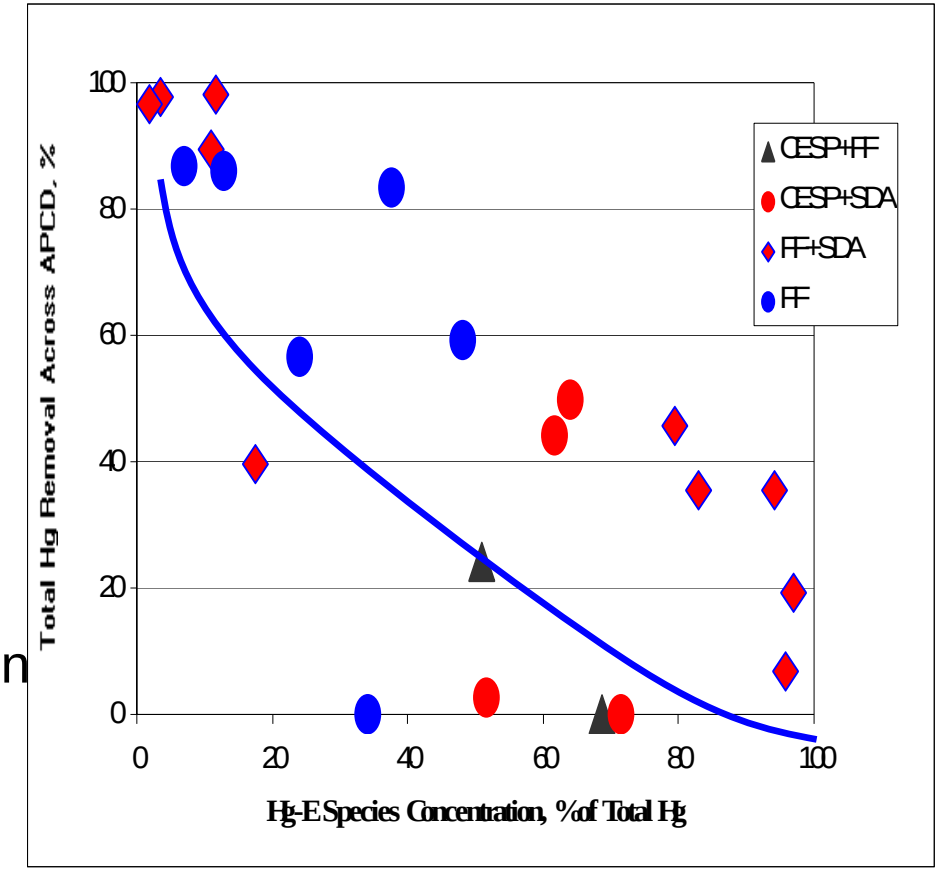
BOILER EQUIPMENT IMPACT ON MERCURY EMISSIONS

- Mercury removal varies across air pollution control devices :
  - Cold-side ESP's ⇗ 20-30%.
  - Hot-side ESP's ⇗ 0-10%.
  - Fabric Filters ⇗ 50-60%.
  - Wet/dry FGD and spray dryer absorbers ⇗ 80-90% of bivalen Hg.
  - SCR ⇗ 40-60%.



Higher fraction of Hg^0 is a problem at the different APCDs.

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IMPACT/IMPORTANCE OF BOILER OPERATING CONDITIONS ON MERCURY

- **The fate of Hg emissions is impacted by the chemical and physical processes occurring in the boiler convective pass and APCDs.**
  - Homogeneous Hg oxidation is a kinetically controlled process occurring in the flue gas. It is affected by flue gas time-temperature trend and composition.
  - Heterogeneous oxidation and adsorption is affected by the combined effect of surface chemical kinetics and mass diffusion. It is promoted by the nature of the fly ash and flue gas conditions and composition.
- **Link between boiler conditions and Hg emissions:**
  - Time-temperature history - flue gas temperature, APH performance, stack flow).
  - Fly ash characteristics - mill classification, low-NO_x firing system operation, fuel blending).
  - Flue gas conditions – excess O_2 level, reduced NO_x emission level.
  - Other links - operating practices, boiler load profile, sootblowing, etc.

These variables ensure that Hg speciation is site-specific.

- **Importance of getting a handle on the operating conditions impacts:**
  - Interpretation of Hg test data.
  - Development of Hg emissions control options.
  - Reduce the cost of compliance.

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BOILER OPTIMIZATION FOR MERCURY CONTROL PROJECT AT THE ERC

- **Feasibility Study (included modeling/review)**
- **Boiler Optimization Project**
- **Activated Carbon Injection Project**
- **Objectives:**
  - Develop technical understanding and analytical model of Hg behavior in the flue gas in relation to appropriate boiler controllable parameters.
  - Investigate the extent of Hg reduction by optimization of boiler operation through field testing at full-scale boilers.
  - Investigate activated carbon injection requirements for Hg compliance in combination with optimized boiler control settings.

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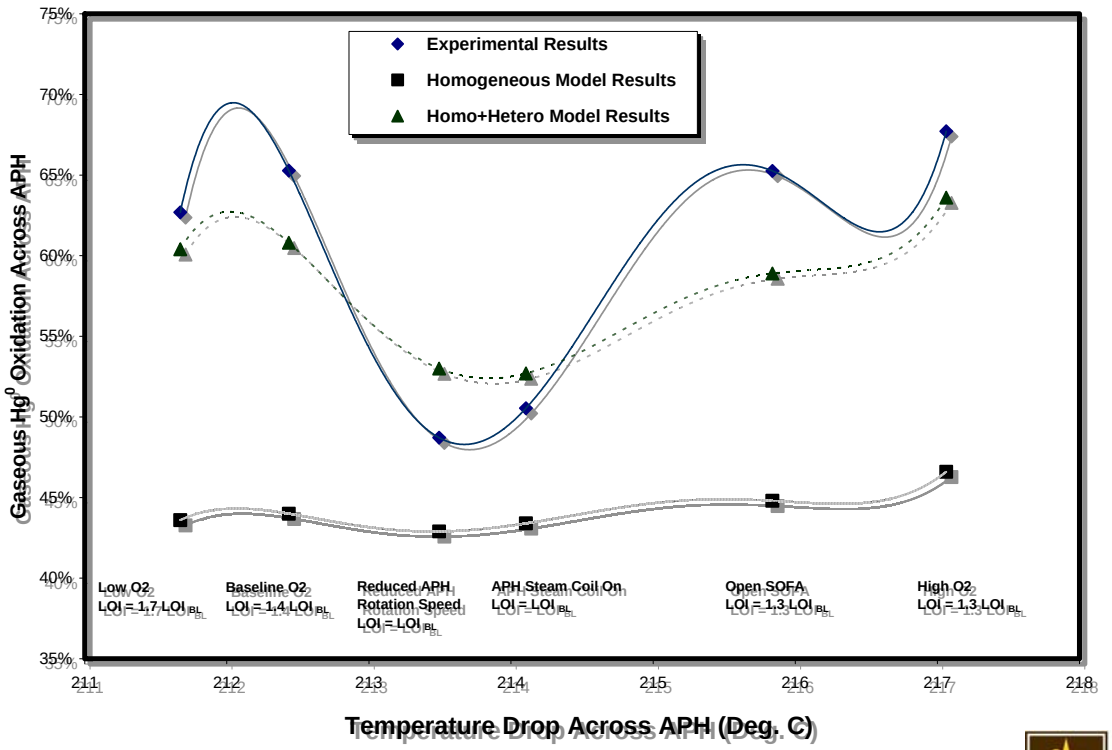
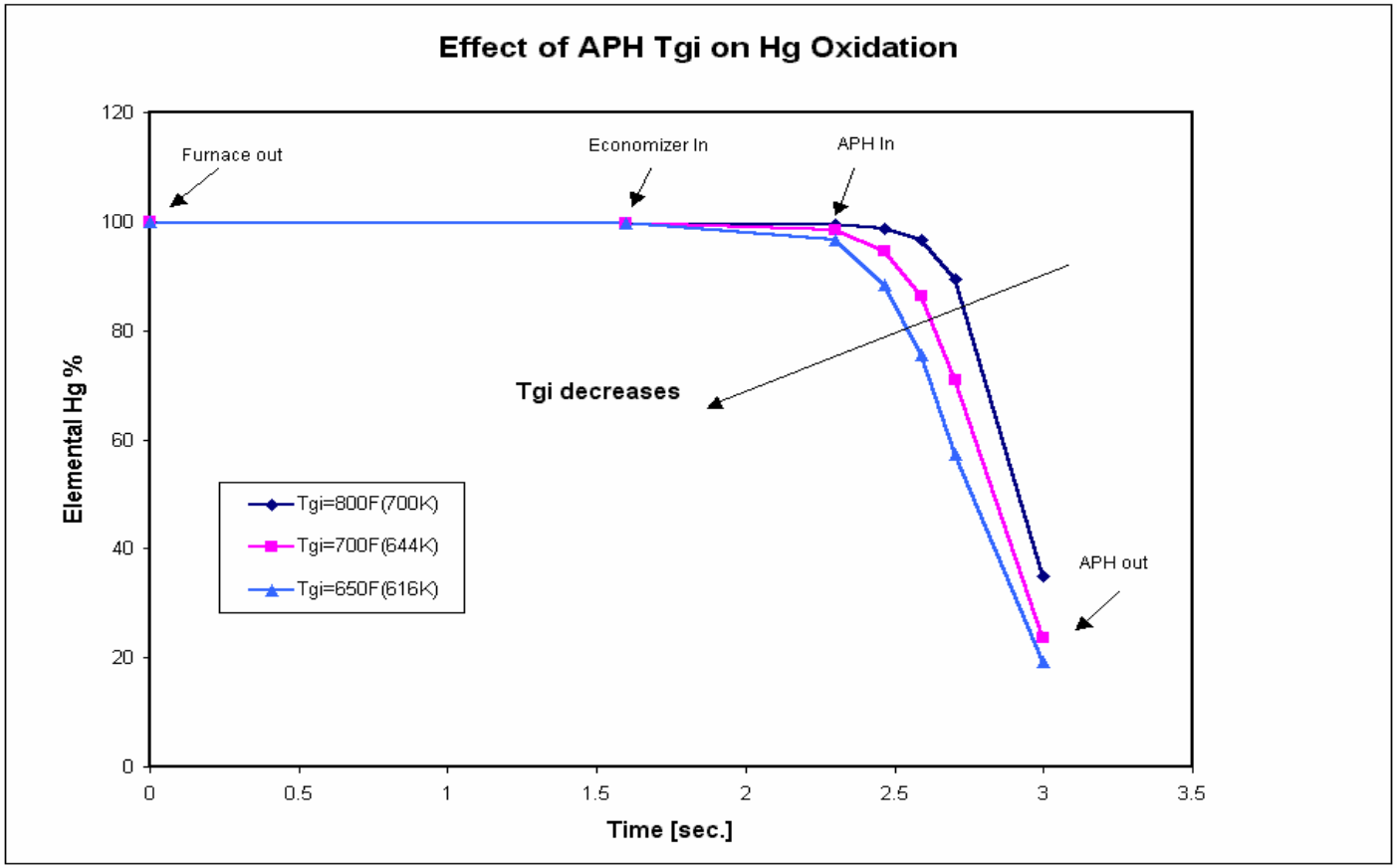
MERCURY MODELING

- Mercury model includes a reaction scheme with 35 species and 92 reactions and the heterogeneous Hg oxidation by fly ash.
- Model validated against a range of datasets.
- Model used to interpret test data and guide parametric testing.



MODEL RESULTS – Effect of APH Gas Inlet Temp. on Hg Oxidation

- Operation of the air preheater impacts the $Hg^0/HgCl_2$ ratio at the air preheater outlet.



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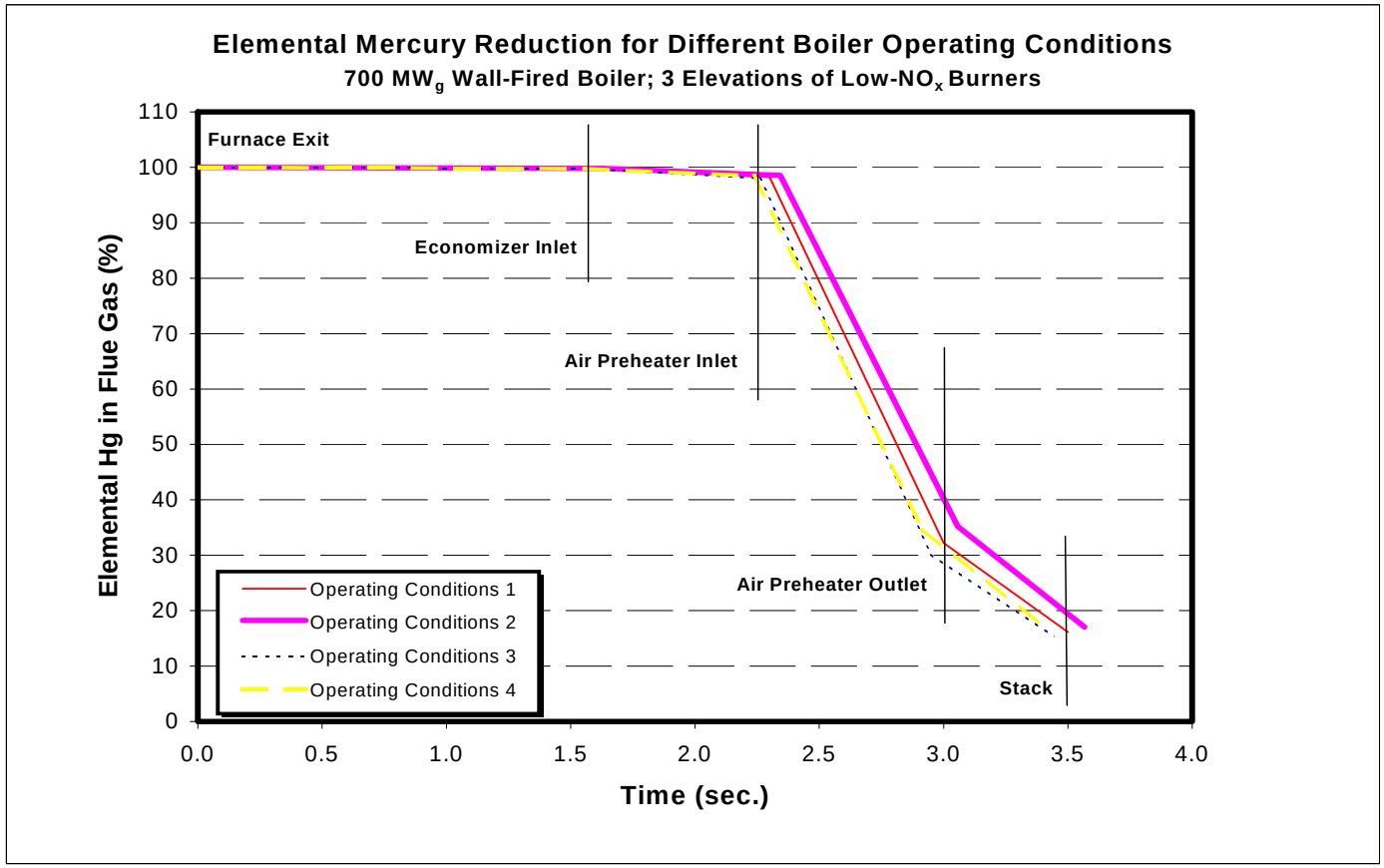
MODEL RESULTS – Example of Boiler Operation vs. Hg Oxidation

- Each trend corresponds to a combination of boiler control settings that result in changes to flue gas conditions and, consequently, the $Hg^0/HgCl_2$ ratio.



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FIELD TESTING

- Testing at three coal-fired units that fire bituminous coals was performed:
  - Site #1 is a 108 MW, T-fired boiler. Cold- and hot-ESP, and tubular APH. Conventional burners. Unit burns low-Sulfur Eastern U.S. bituminous coal.
  - Site #2 is a 250 MW, T-fired boiler. Rotating APH with two cold ESP's in series. LNCFS-III low-NO_x firing system. Unit burns U.S. bituminous and imported coals.
  - Site #3 is a 650 MW, opposed wall-fired boiler. Rotating APH with two cold ESP's in series. DRB-XCL low-NO_x burners with OFA. Unit burns U.S. bituminous and imported coals.

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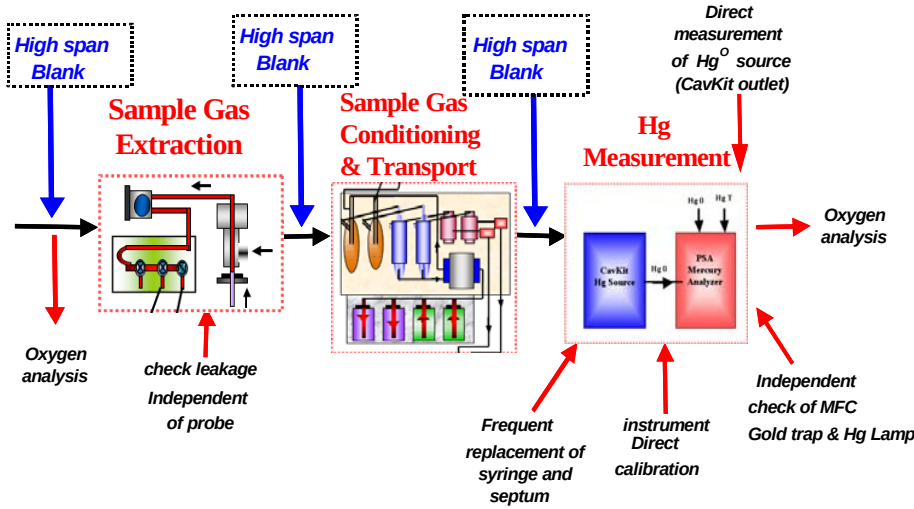
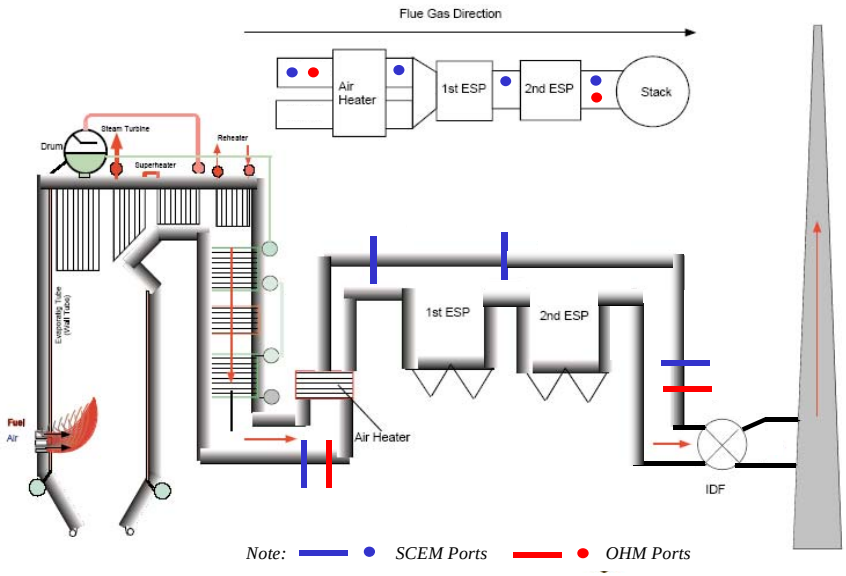
FIELD TESTING

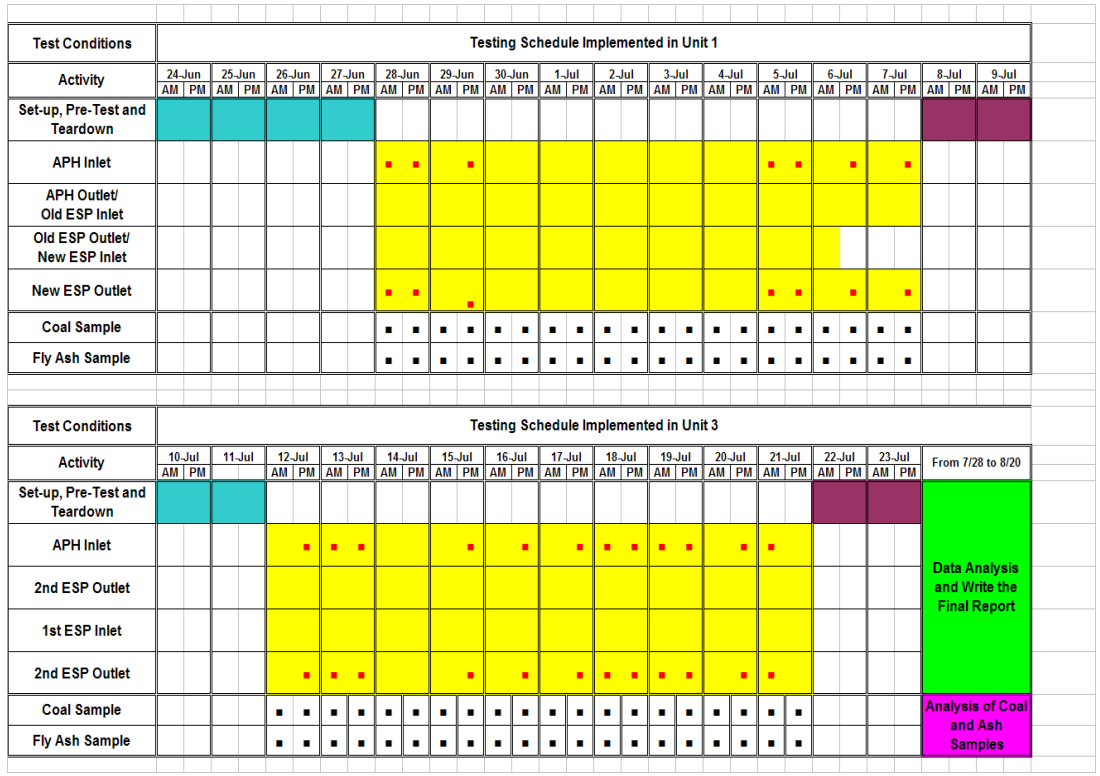
- Analytical capabilities:
  - Baldwin and Apogee inertial filtration probes.
  - Pretreatment/conditioning units.
  - PSA SCEM's for Hg speciation.
  - OHM with EPA Method 17 (performed on-site).
  - Coal, pyrite and fly ash analyses (ultimate and proximate analyses, Hg, Cl, S, LOI).





FIELD TESTING

- Feasibility phase involved five days of boiler manipulation per boiler.
- Boiler optimization project at two units involved a ten-day test schedule that included baselining, parametric testing, and optimal condition tests.
- Parameters investigated: unit load, excess air, OFA settings, mill bias and O/S configuration and classification, APH back-end temperature, ESP energization and rapping, and sootblowing.
- AC injection project involved testing at different AC conditioning rates under normal and optimal low-Hg operating conditions.



Sample Boiler Optimization Schedule

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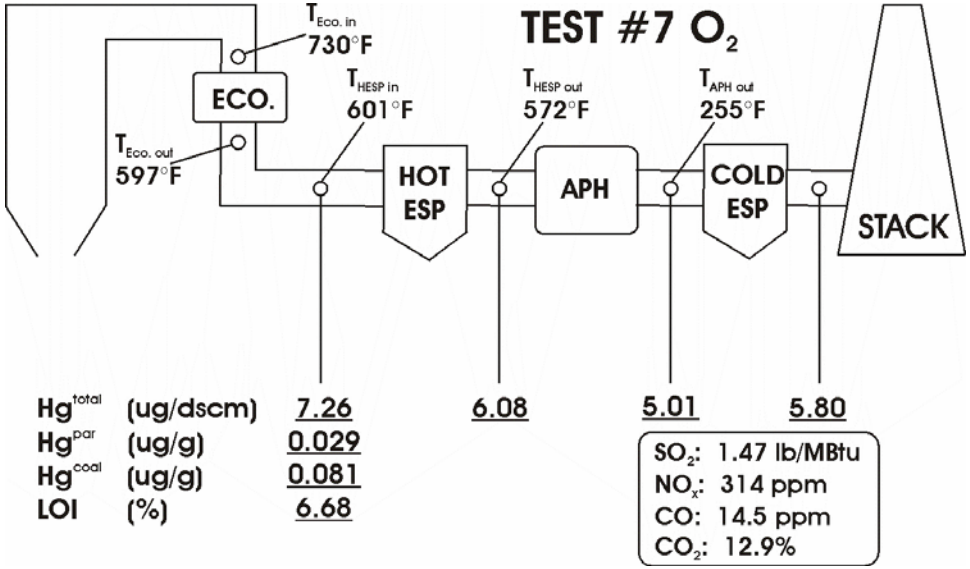
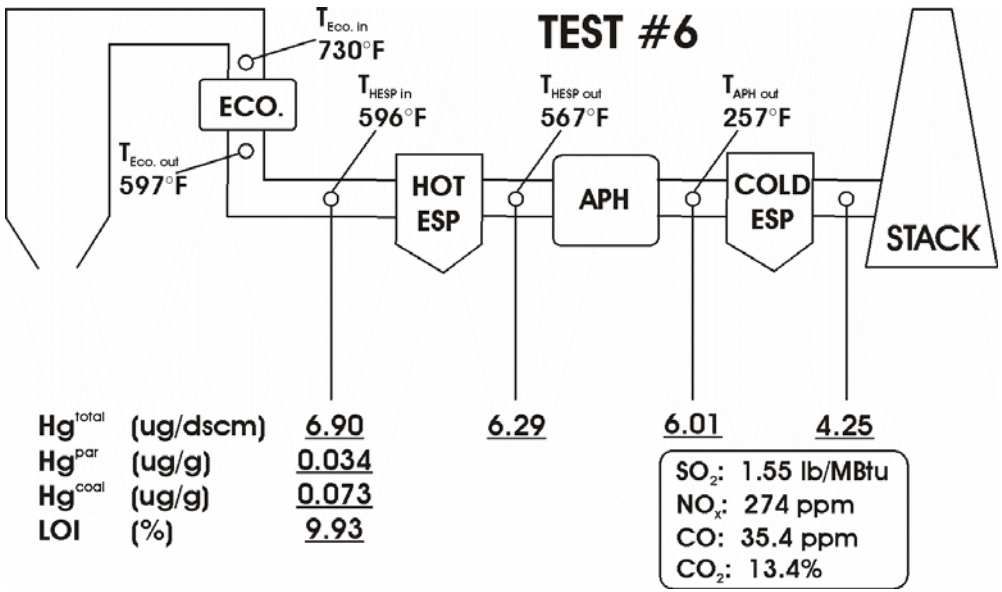
Field Test Results – Site #1



Overall Removal Efficiency = 20.0%
Average Excess O_2 = 2.69%
Fly Ash LOI = 6.68%



Overall Removal Efficiency = 38.4%
Average Excess O_2 = 2.13%
Fly Ash LOI = 9.93%

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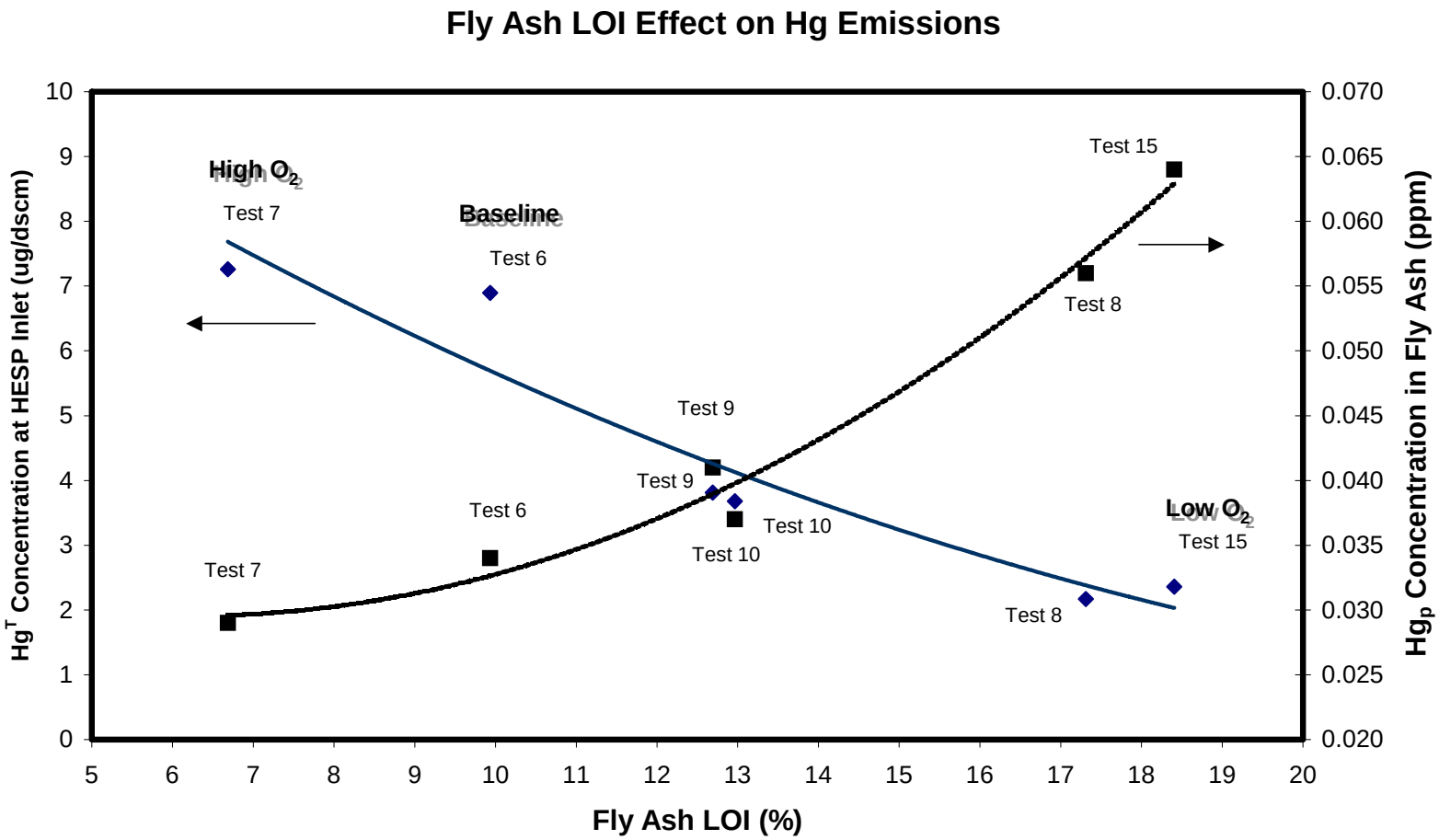
Field Test Results – Site #1



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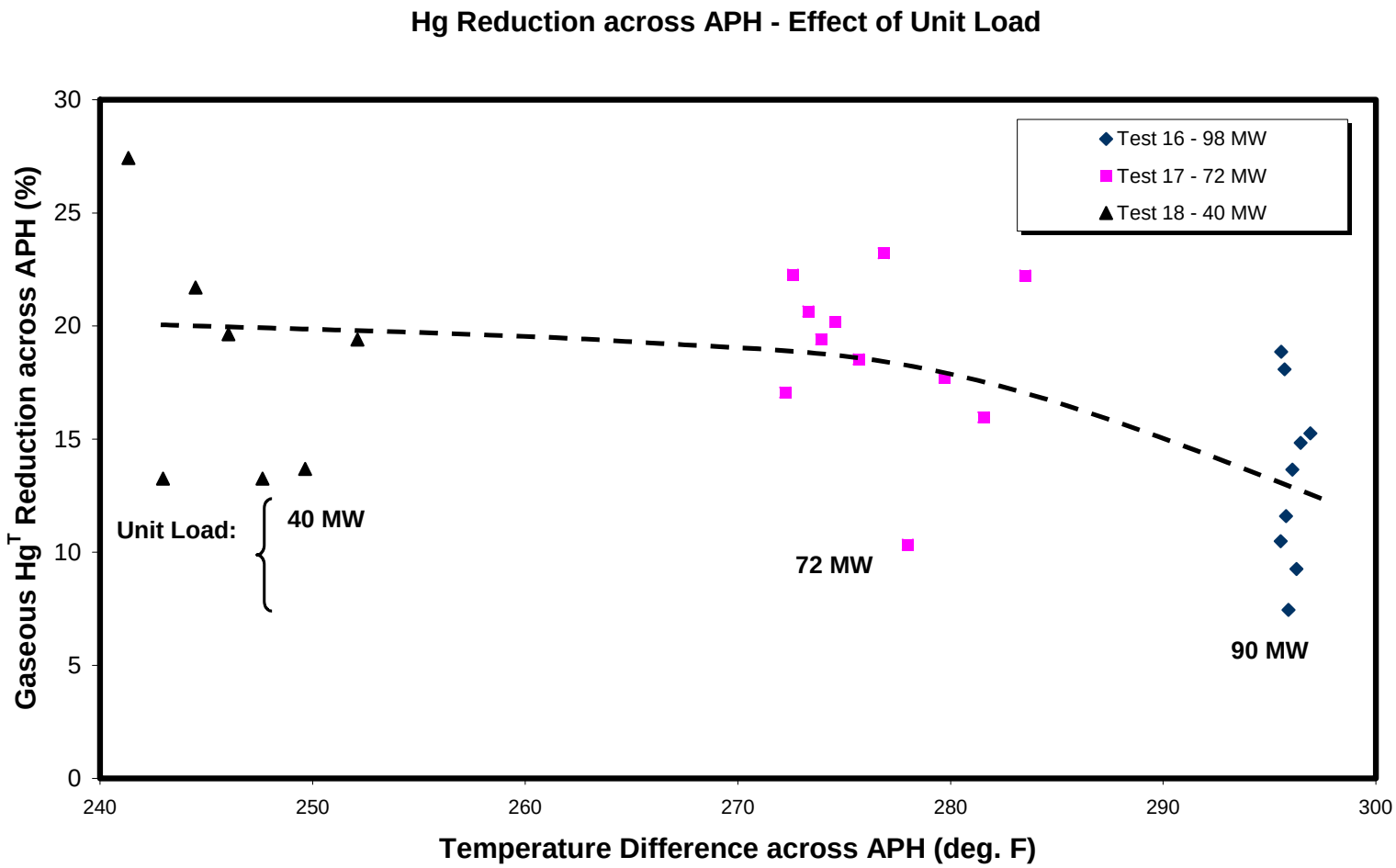
Field Test Results – Site #1



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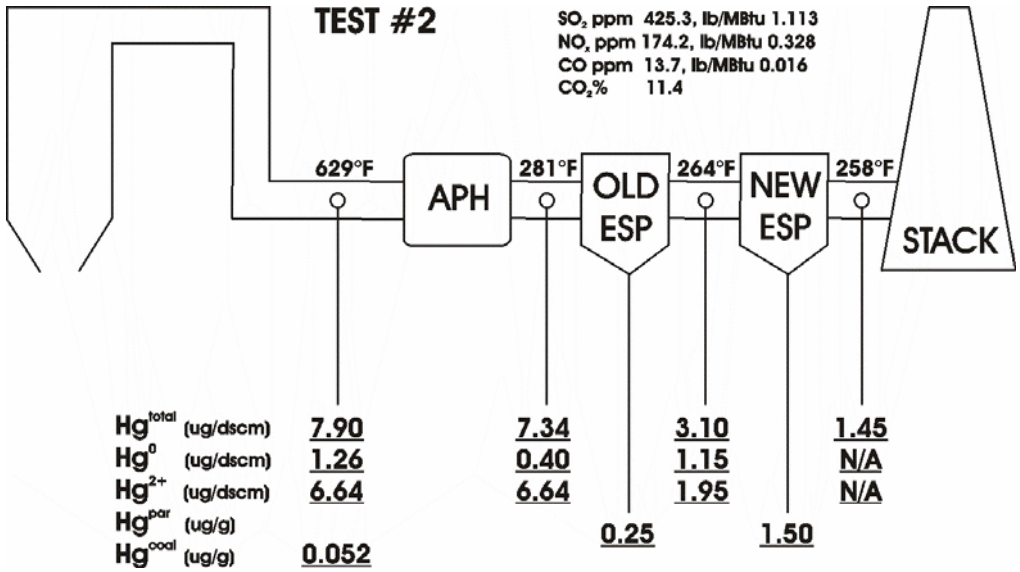
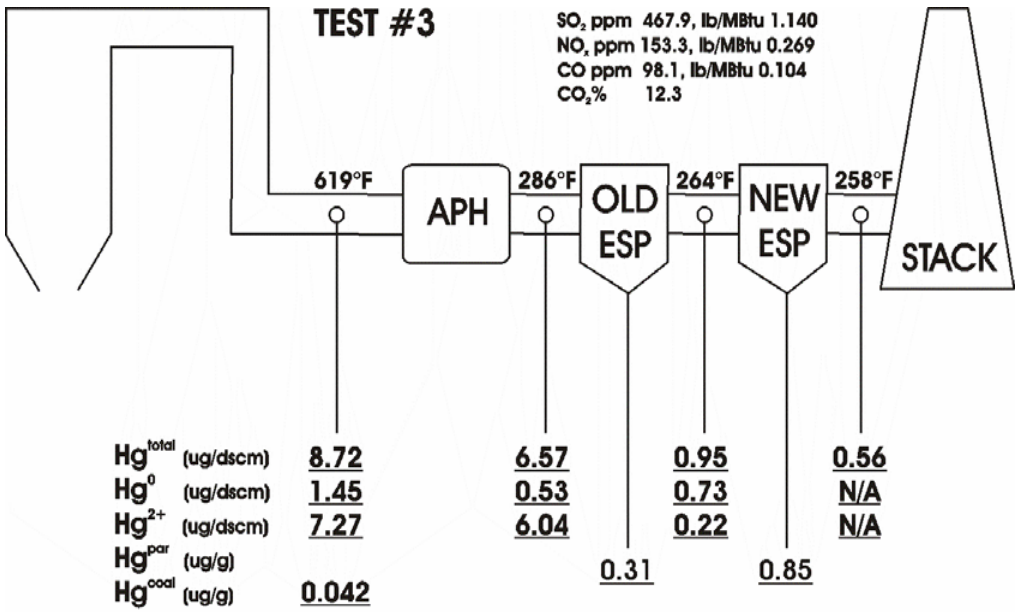
Field Test Results – Site #2



Overall Removal Efficiency = 81.6%
Average Excess O_2 = 3.5%
Fly Ash LOI = 17.4%



Overall Removal Efficiency = 93.6%
Average Excess O_2 = 1.8%
Fly Ash LOI = 22.3%

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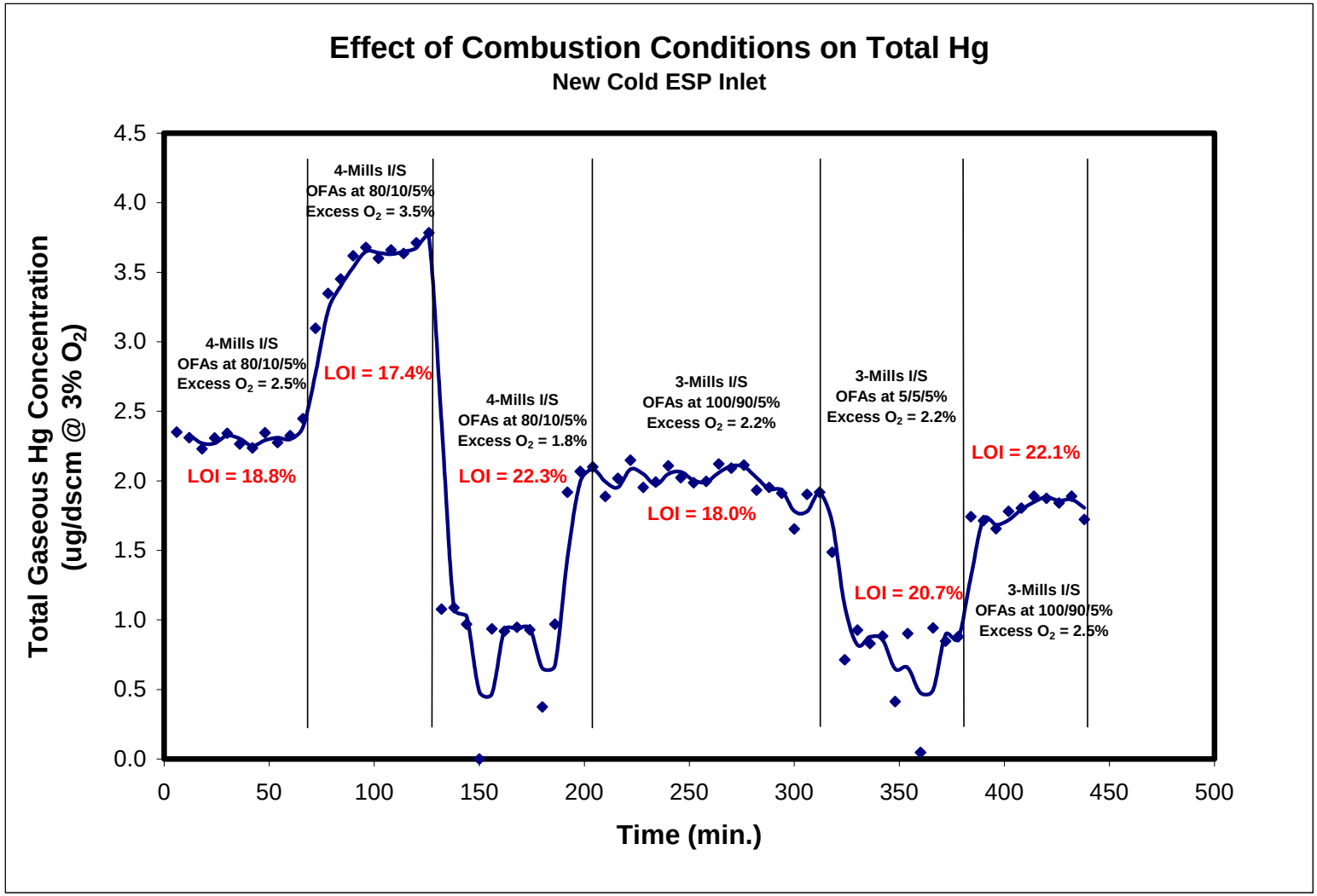
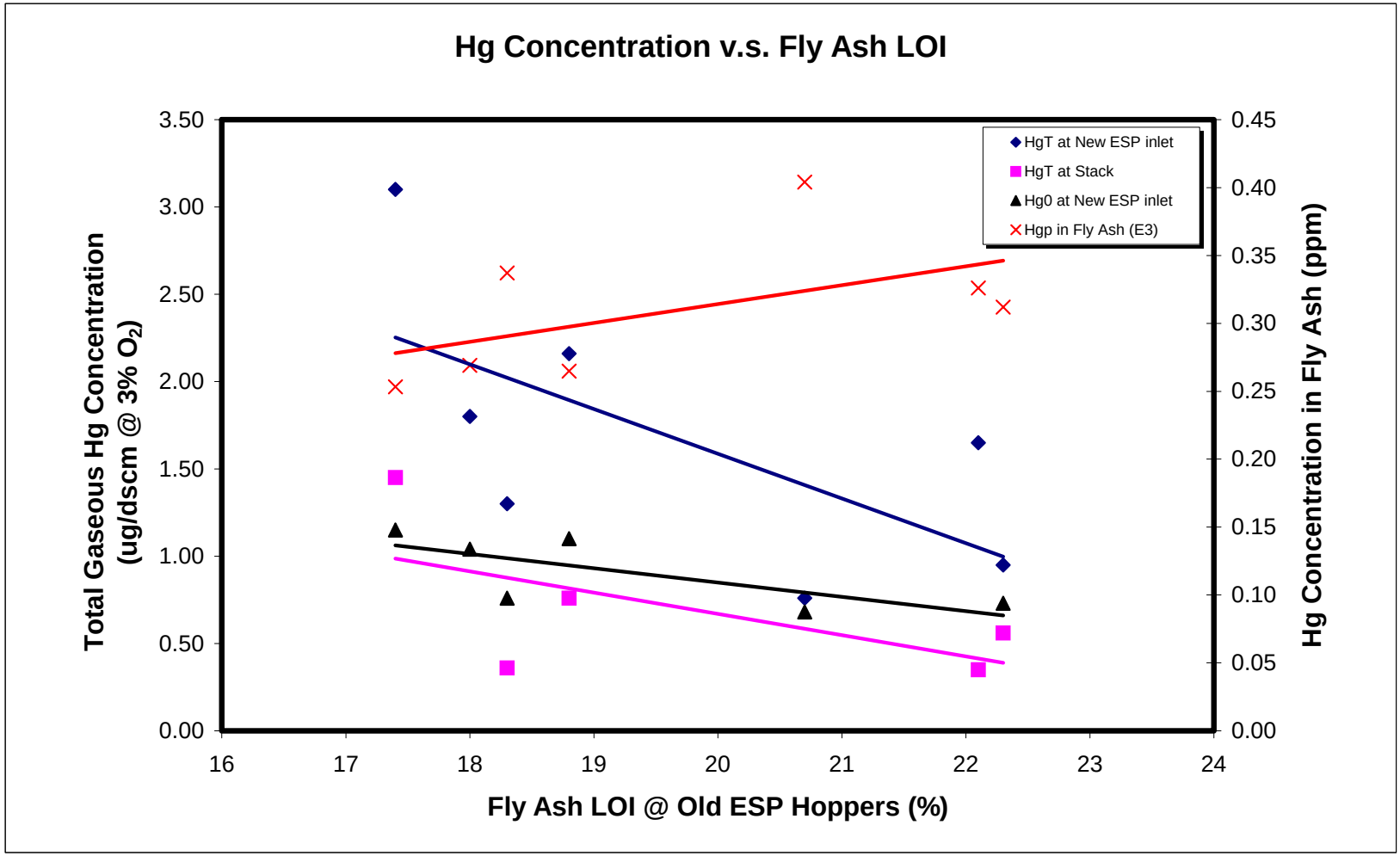
Field Test Results – Site #2



Field Test Results – Site #2



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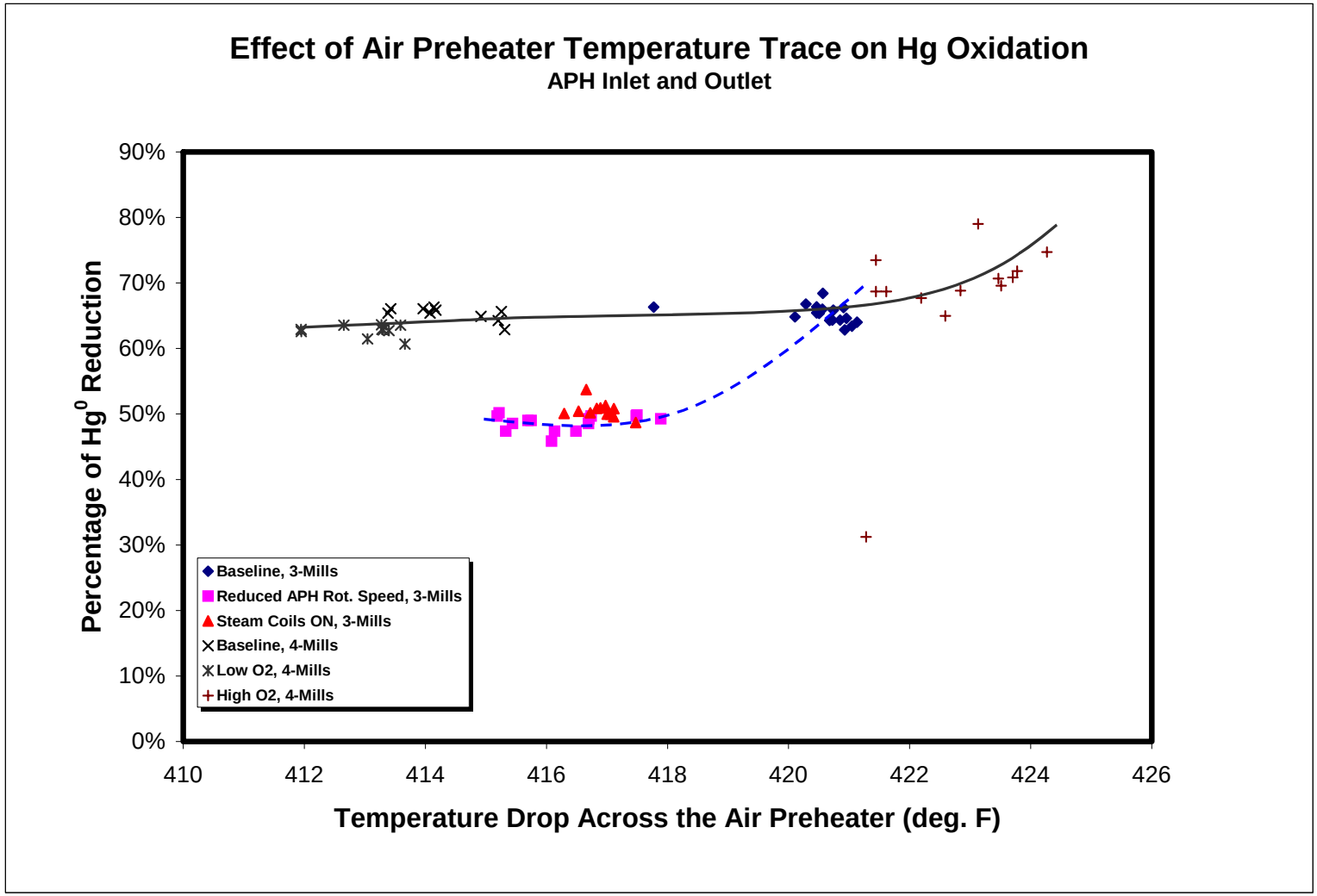

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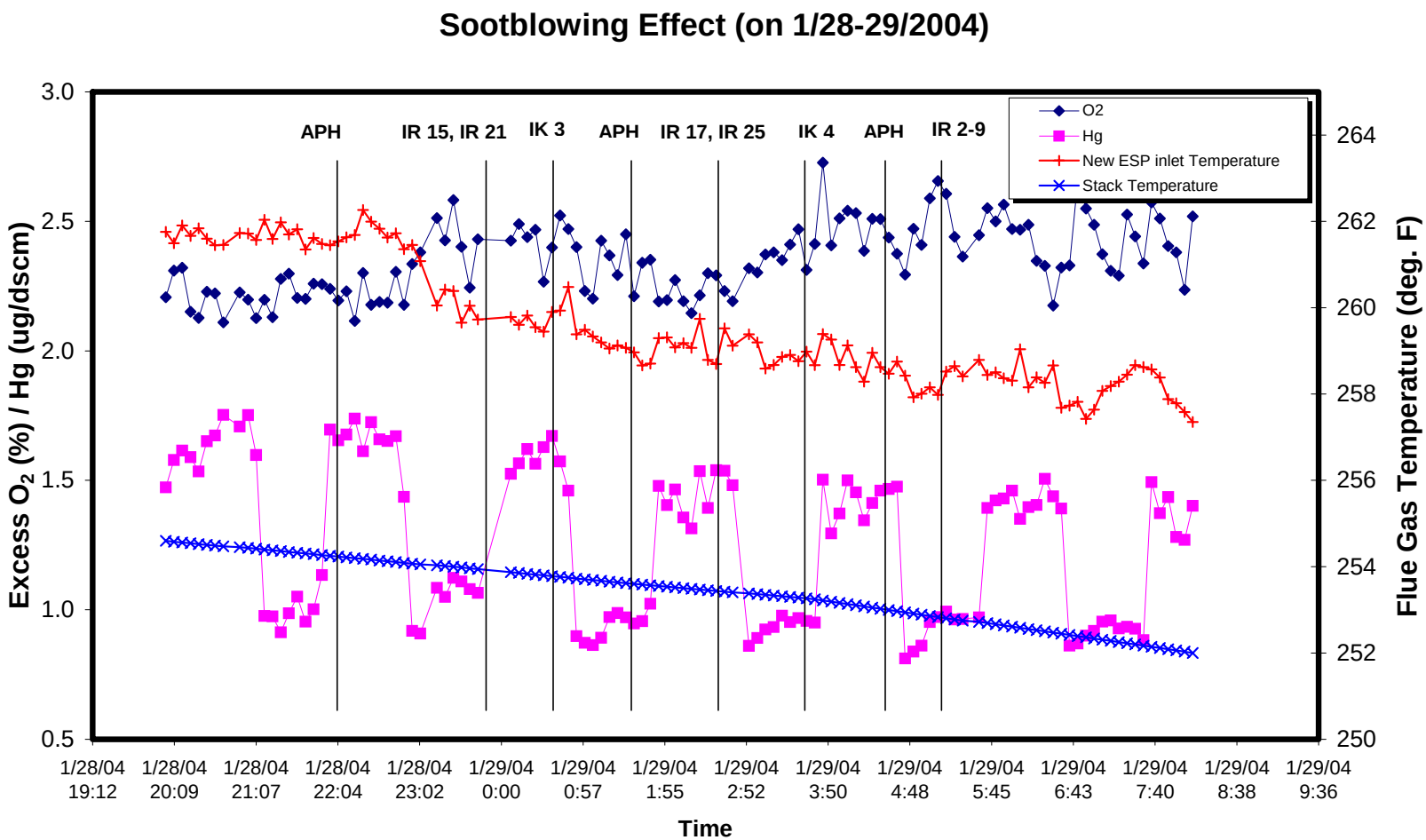

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IMPACT OF COMBUSTION CONDITIONS ON Hg

Operating Conditions	Day	Date	Start	End	Mills in Service	Classifier Setting	O2 Trim	SOFAs (80/90/100)	Burner Tilt	SOFA Tilt	Steam Coils	Old ESP
Baseline - High Hg	Sunday	7/4/04	7/4/04 13:30	7/4/04 15:10	All	6/5	66.0	5/5/05	0	0	SHUT	ON
Low-NOx	Monday	6/28/04	6/28/04 14:00	6/28/04 15:00	All	6/5	56.5	70/30/5	-10	20	SHUT	ON
Low-NOx	Tuesday	6/29/04	6/29/04 13:15	6/29/04 14:15	All	6/5	56.5	70/30/5	-10	20	SHUT	ON
Low O2	Wednesday	6/30/04	6/30/04 12:10	6/30/04 13:15	All	6/5	43.0	70/30/5	-10	20	SHUT	ON
Low O2+SOFA	Wednesday	6/30/04	6/30/04 15:30	6/30/04 17:30	All	6/5	43.6	100/80/5	-10	20	SHUT	ON
Low-NOx	Thursday	7/1/04	7/1/04 8:45	7/1/04 10:15	All	6/5	56.5	70/30/5	-10	20	SHUT	ON
Mid O2+SOFA	Thursday	7/1/04	7/1/04 12:01	7/1/04 14:00	All	6/5	47.0	100/80/5	-10	20	SHUT	ON
Mid O2+SOFA+Class.	Thursday	7/1/04	7/1/04 17:00	7/1/04 19:30	All	4	47.0	100/80/5	-10	20	SHUT	ON
Mid O2+SOFA+Class.+Coils	Friday	7/2/04	7/2/04 12:01	7/2/04 14:00	All	4	47.0	100/80/5	-10	20	100%	ON
Mid O2+SOFA+Class.+Coils+14Mill OFF	Friday	7/2/04	7/2/04 16:00	7/2/04 17:28	14 Off	4	50.0	100/80/5	-10	20	100%	ON
Mid O2+SOFA+Class.+Coils+11Mill OFF	Friday	7/2/04	7/3/04 19:00	7/3/04 20:38	11 Off	4	52.0	100/80/5	-10	20	100%	ON
Mid O2+SOFA+Class.+Coils+Old ESP OFF	Saturday	7/3/04	7/3/04 13:30	7/3/04 15:30	All	4	42.0	100/80/5	-10	20	100%	OFF
Low-Hg Settings	Sunday	7/4/04	7/4/04 19:40	7/4/04 21:50	All, Biased	4	38.0	100/80/5	-10	20	40%	OFF
Low-Hg Settings (with Mid O2)	Tuesday	7/6/04	7/6/04 16:45	7/6/04 20:00	All, Biased	4	45.0	100/80/5	-10	20	40%	OFF

Operating Conditions	SCEM (corr. to 3% O2)								OHM (corr. to 3% O2)				SCEM	Delta
	APHin Hg(0)	APHin Hg(T)	APHout Hg(0)	APHout Hg(T)	ESPin Hg(0)	ESPin Hg(T)	ESPout Hg(0)	ESPout Hg(T)	APHin Hg(0)	APHin Hg(T)	ESPout Hg(0)	ESPout Hg(T)	Removal Efficiency	Hg(T) at Stack
Baseline - High Hg	1.465	6.491	0.856	7.342	2.227	4.155	1.088	6.104	7.68	8.47	1.28	4.89	5.96	0.00
Low-NOx	1.953	4.539	0.719	6.546	0.474	0.835	1.201	3.695	7.86	9.25	0.79	3.93	18.58	-2.41
Low-NOx	2.424	6.092	1.573	6.269	1.943	3.403	0.423	3.018	3.66	4.82	1.31	4.39	50.46	-3.09
Low O2	1.047	7.085	0.000	3.227	1.123	2.287	0.792	2.797					60.52	-0.56
Low O2+SOFA	0.352	5.818	0.504	3.659	1.029	2.188	0.632	2.422					58.37	-0.37
Low-NOx	2.128	6.530	0.865	6.048	1.210	2.123	0.913	3.644					44.20	-2.46
Mid O2+SOFA	1.899	6.746	0.710	2.979	0.873	0.961	1.026	3.414					49.39	-0.23
Mid O2+SOFA+Class.	2.193	7.108	0.610	4.243	0.129	0.552	1.375	2.862					59.74	-0.55
Mid O2+SOFA+Class.+Coils	1.451	4.298	0.687	3.930	1.016	2.626	1.401	3.334					22.42	0.47
Mid O2+SOFA+Class.+Coils+14Mill OFF	1.364	4.553	0.325	3.937	0.417	2.125	0.622	2.252					50.54	-1.08
Mid O2+SOFA+Class.+Coils+11Mill OFF	1.588	4.520	0.602	2.944	0.000	4.280	1.032	3.436					23.97	0.10
Mid O2+SOFA+Class.+Coils+Old ESP OFF	1.473	6.997	1.057	6.723	0.300	1.084	0.474	1.658					76.31	-1.68
Low-Hg Settings	1.230	5.627	0.640	3.328	0.160	0.552	0.398	1.731	7.39	7.96	1.31	3.98	69.24	-4.37
Low-Hg Settings (with Mid O2)	1.782	7.228	0.825	5.695	0.401	2.327	0.811	2.954	7.06	8.08	1.08	3.92	59.13	-3.15

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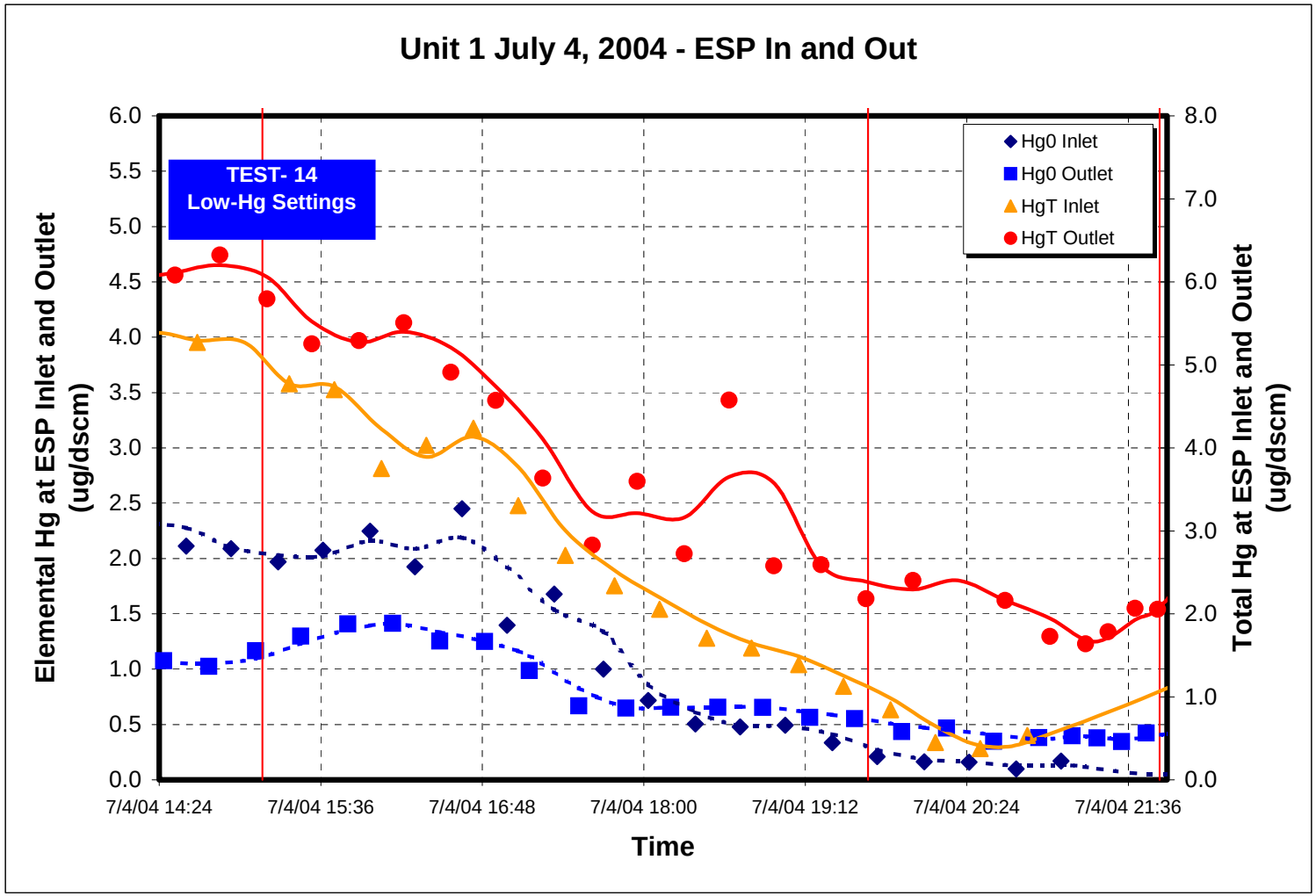
Field Test Results – Site #2



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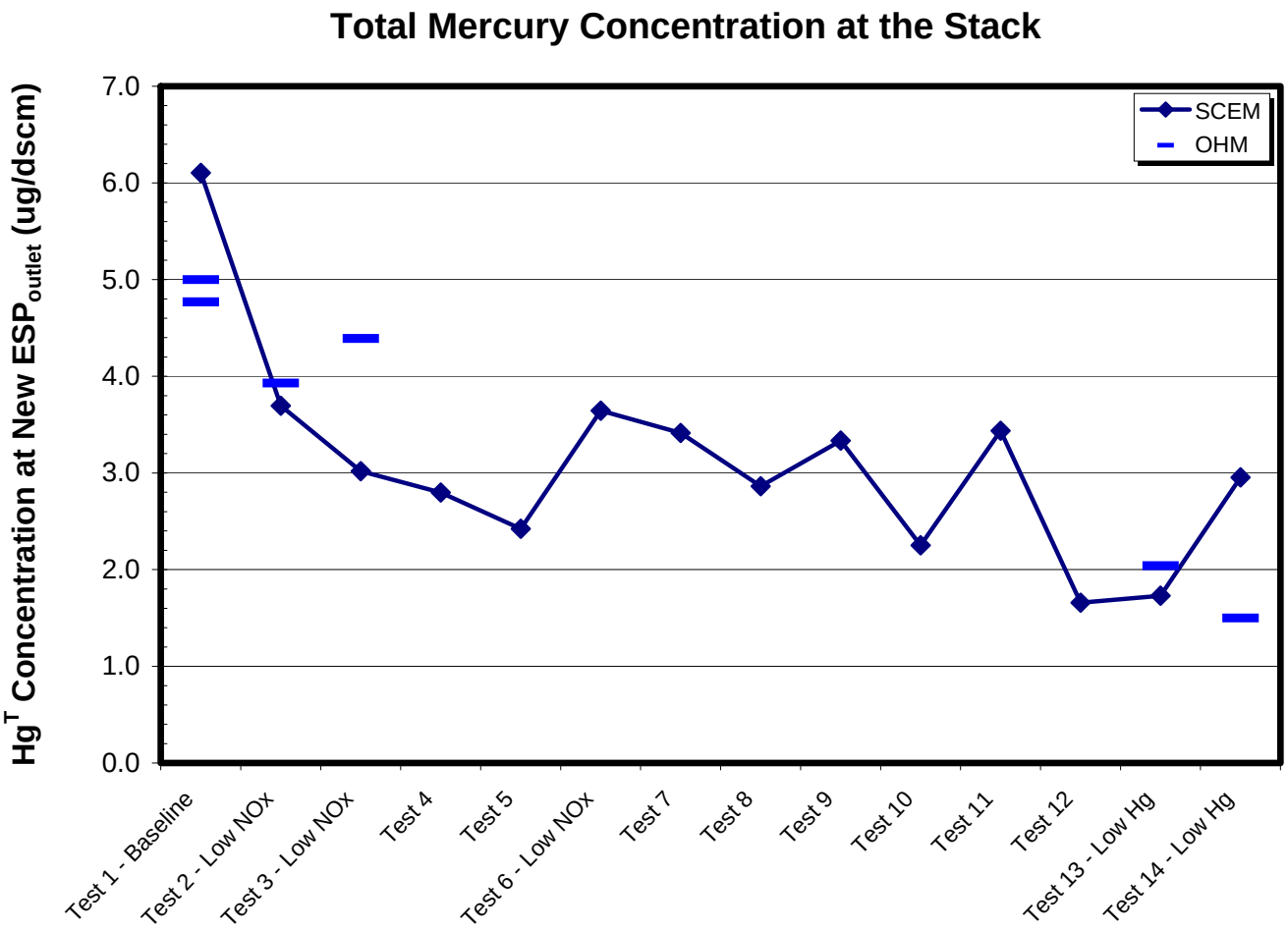

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IMPACT OF COMBUSTION CONDITIONS ON Hg

Operating Conditions	Day	Date	Start	End	Mills in Service	Classifier Speed	O2 Trim	Steam Coils	Old ESP
Baseline - High Hg	Monday	7/12/04	16:00	19:00	All	100	79	OFF	ON
Baseline - High Hg	Tuesday	7/13/04	12:30	15:00	All	100	80	OFF	ON
Baseline - High Hg	Tuesday	7/13/04	15:30	18:00	All	100	80	OFF	ON
Baseline - High Hg	Wednesday	7/14/04	10:30	13:15	All	100	80	OFF	ON
Low O2+Class.	Thursday	7/15/04	13:00	16:30	All	85	69	OFF	ON
Low O2+Class.+Old ESP OFF	Thursday	7/15/04	17:30	21:00	All	85	66	OFF	OFF
Low O2+Class.+Old ESP OFF	Friday	7/16/04	15:30	21:20	All	85	68	OFF	OFF
Mid O2+Class.+Old ESP OFF+32 Mill OFF	Saturday	7/17/04	11:30	14:50	32 OFF	85	71	OFF	OFF
Mid O2+Class.+Old ESP OFF+32 Mill OFF	Sunday	7/18/04	14:00	16:00	32 OFF	85	75	OFF	OFF
Mid O2+Class.+Old ESP OFF+32 Mill OFF	Sunday	7/18/04	17:45	20:30	32 OFF	85	71	OFF	OFF
Mid O2+Class.+Old ESP OFF+31 Mill OFF	Monday	7/19/04	12:35	15:00	31 OFF	85	71	OFF	OFF
Mid O2+Class.+Old ESP OFF+31 Mill OFF	Monday	7/19/04	16:35	18:45	31 OFF	85	71	OFF	OFF
Baseline - High Hg	Tuesday	7/20/04	11:30	14:30	All	100	77	OFF	ON
Baseline+34 Mill OFF	Wednesday	7/21/04	11:00	13:25	34 OFF	100	78	OFF	ON

Operating Conditions	SCEM (corr. to 3% O2)								OHM (corr. to 3% O2)				SCEM	Delta
	APHin Hg(0)	APHin Hg(T)	APHout Hg(0)	APHout Hg(T)	ESPin Hg(0)	ESPin Hg(T)	ESPout Hg(0)	ESPout Hg(T)	APHin Hg(0)	APHin Hg(T)	ESPout Hg(0)	ESPout Hg(T)	Removal Efficiency	Hg(T) at Stack
Baseline - High Hg	0.770	6.340	0.900	2.260	2.690	5.680	0.700	5.570	3.77	4.01	1.74	6.09	12.1	0.00
Baseline - High Hg	0.410	5.310	0.450	3.360	2.790	6.090	1.480	4.910	5.37	6.29	1.76	5.90	7.5	0.00
Baseline - High Hg	0.424	5.299	0.800	2.700	NA	NA	1.119	5.060	5.67	6.63	1.97	5.73	4.5	0.00
Baseline - High Hg	0.870	5.720	1.470	4.370	2.370	5.870	1.650	4.870					14.9	0.00
Low O2+Class.	NA	5.490	0.170	3.490	1.160	3.630	1.070	3.710					32.4	-1.39
Low O2+Class.+Old ESP OFF	0.240	5.310	0.280	3.660	0.910	3.110	1.050	3.500	3.37	4.00	0.52	2.20	34.1	-0.21
Low O2+Class.+Old ESP OFF	0.350	5.080	1.450	4.150	0.460	2.780	1.030	2.780	4.00	4.42	1.10	3.40	45.3	-0.93
Mid O2+Class.+Old ESP OFF+32 Mill OFF	0.350	6.540	1.360	4.140	0.470	1.540	0.760	2.750	3.75	4.10	0.59	2.10	58.0	-0.03
Mid O2+Class.+Old ESP OFF+32 Mill OFF	0.430	6.990	2.830	5.570	0.430	2.780	0.950	2.140	4.50	5.04	1.36	4.80	69.4	-0.64
Mid O2+Class.+Old ESP OFF+32 Mill OFF	0.390	6.520	2.920	5.240	0.410	0.900	1.110	2.140	4.51	4.99	0.92	2.76	67.2	-0.64
Mid O2+Class.+Old ESP OFF+31 Mill OFF	0.310	6.070	0.590	2.700	0.180	1.450	0.810	2.050	4.22	5.04	0.53	1.17	66.2	-0.09
Mid O2+Class.+Old ESP OFF+31 Mill OFF	0.330	5.810	0.880	3.310	0.210	1.320	0.810	2.090	4.36	5.19	0.45	0.89	64.0	-0.05
Baseline - High Hg	0.430	6.520	2.840	5.290	0.440	2.170	0.940	3.180	4.49	4.93	1.01	4.80	51.2	0.00
Baseline+34 Mill OFF	0.590	6.500	3.160	5.460	0.680	4.030	1.360	4.720	4.69	5.30	1.22	4.98	27.4	0.00

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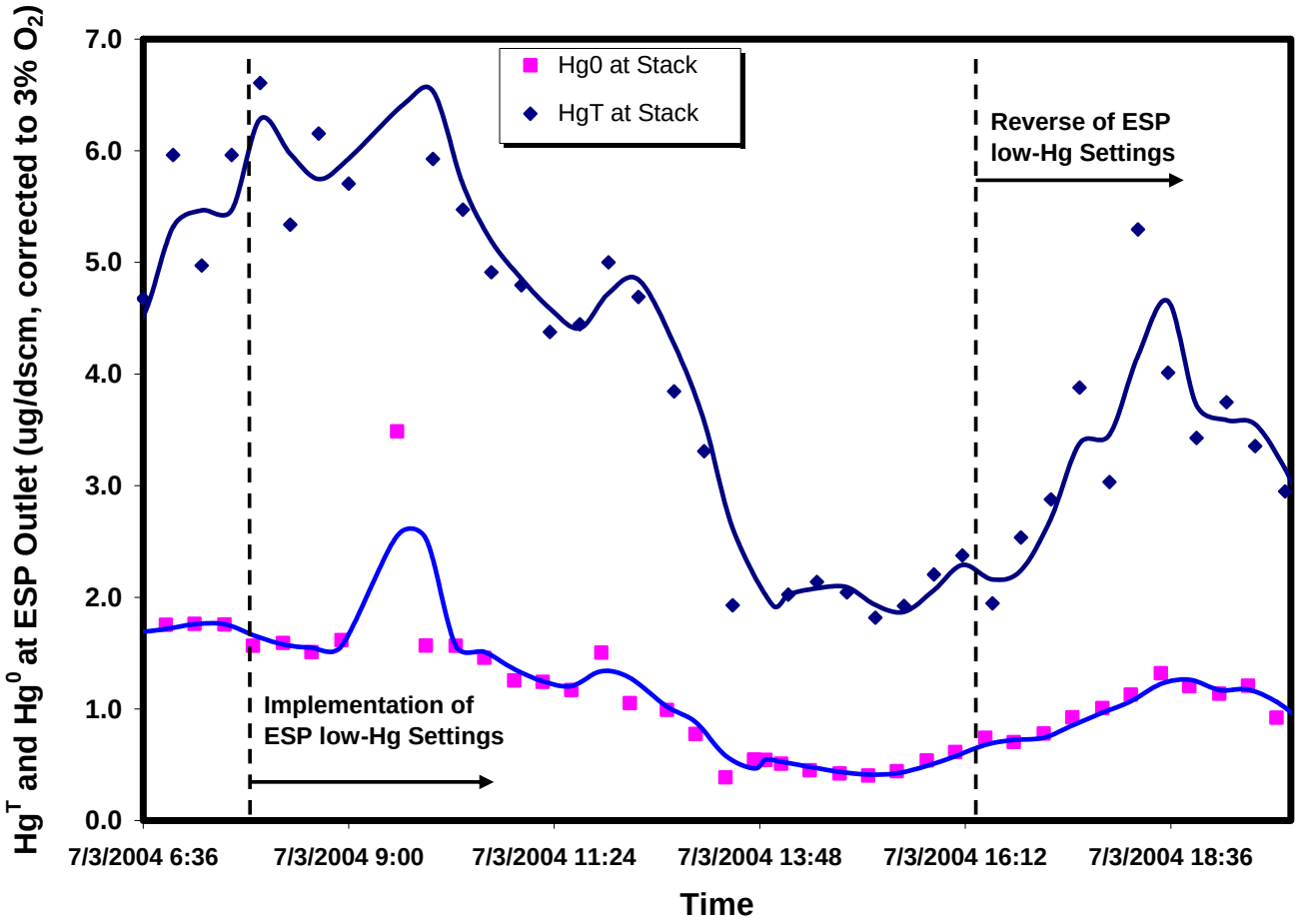
IMPACT OF ESP OPERATION ON



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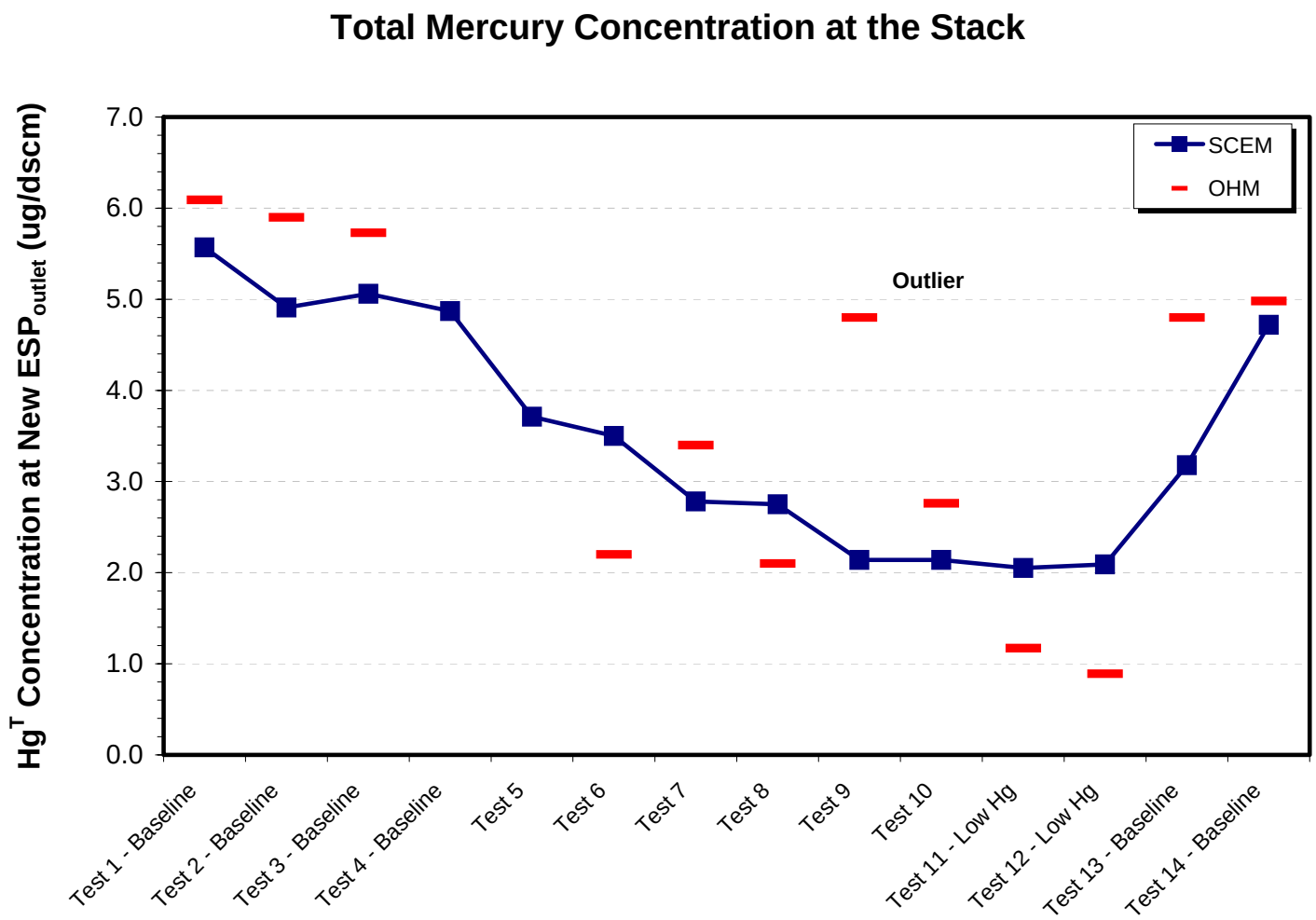
Field Test Results – Site #3



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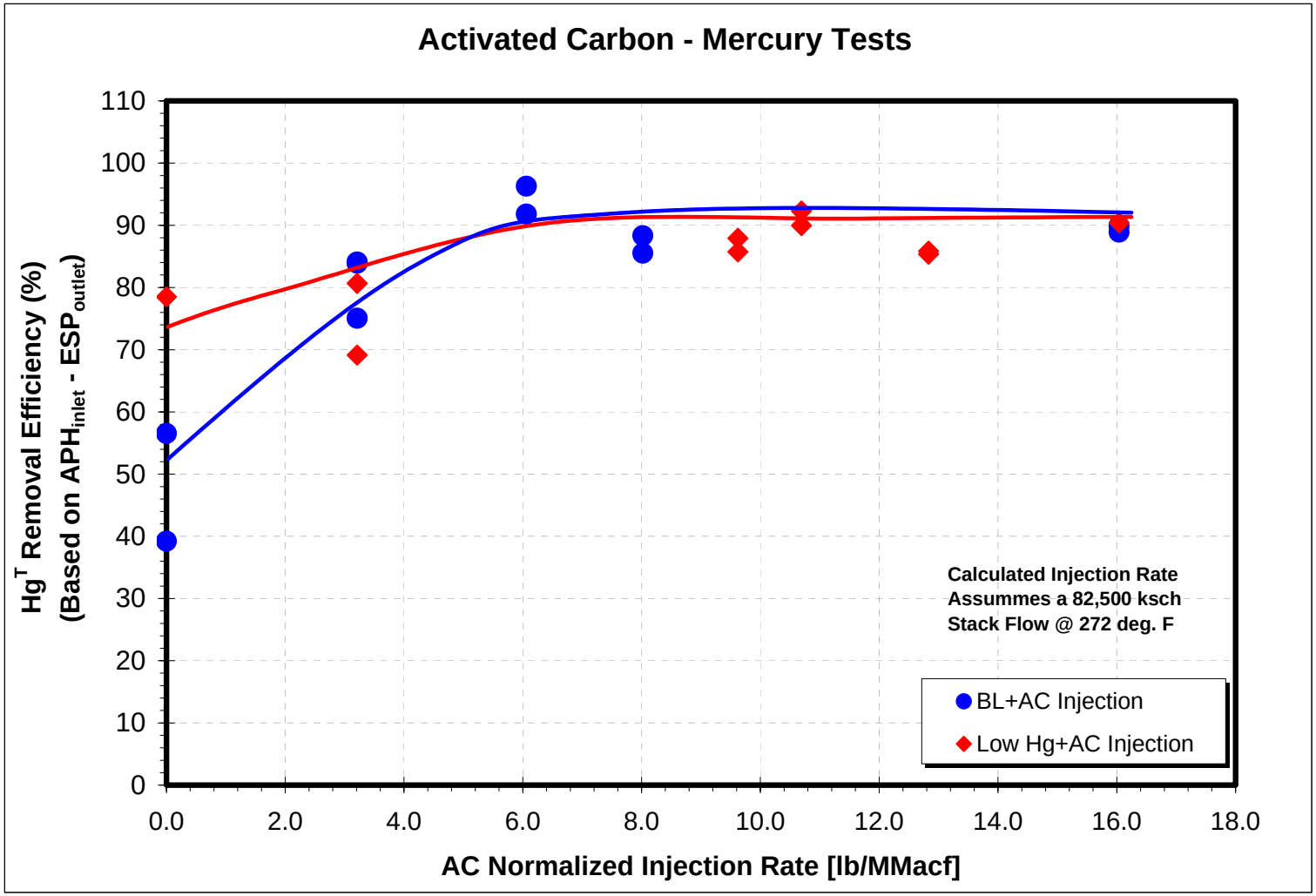
Field Test Results – Site #3



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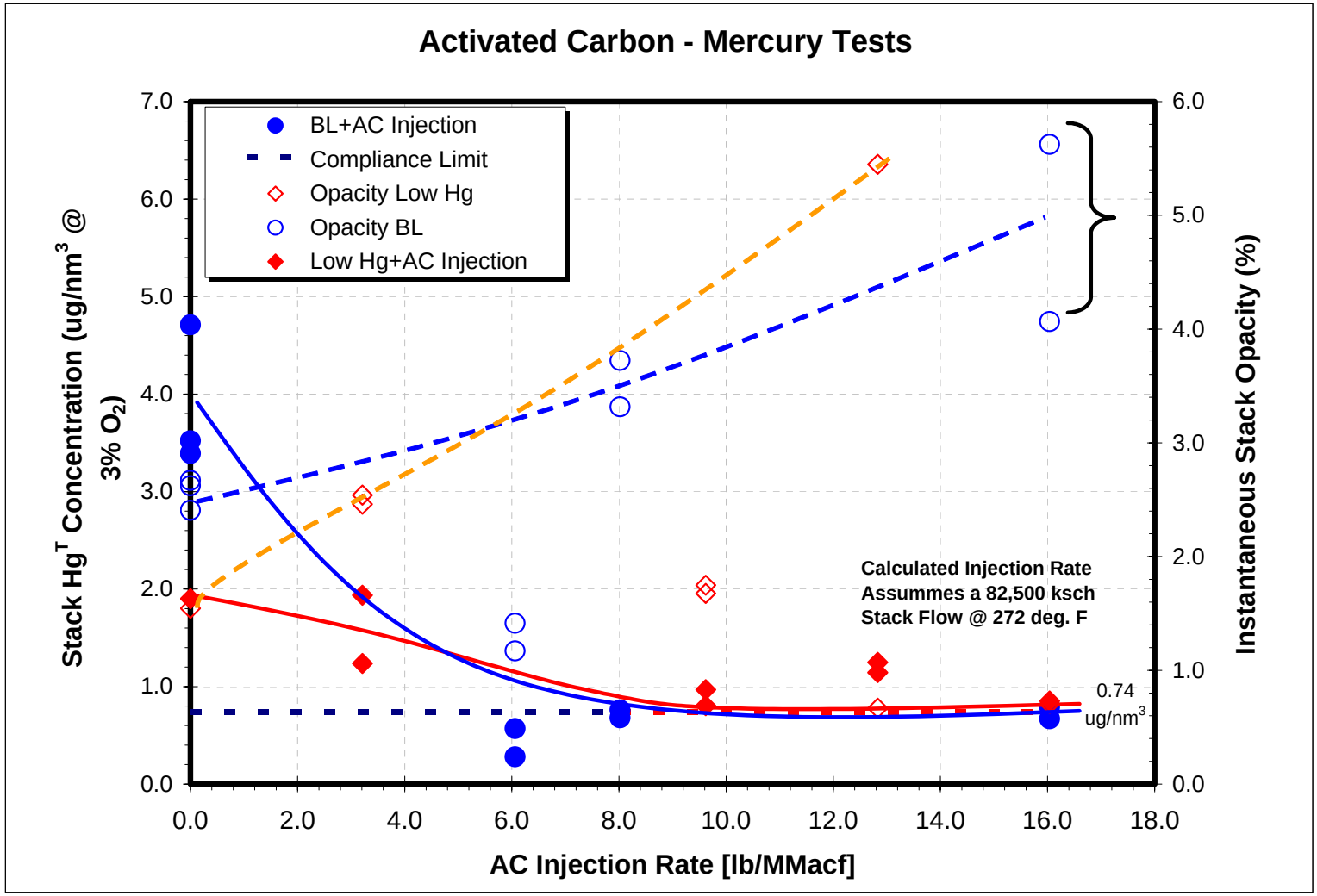
Field Test Results – **Site #3**



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CONCLUSIONS

- Mercury regulations are an urgent issue for the power industry. Low-cost reductions in the 30-50 % range are attractive.
- Analytical and experimental studies have suggested that boiler operating conditions can influence mercury oxidation and emissions from coal-fired boilers.
- Target parameters are: residence time (in-flight capture), flue gas temperature, and fly ash size and unburned carbon level.
- Testing performed at three units, rated at 108, 250 and 650 MW, burning bituminous coals confirms the merit of optimizing boiler operation through changes to the control settings for mercury emissions reduction.
- An optimization test strategy involves unit baselining, parametric testing, extended test at optimal conditions and testing to determine AC requirement for trim control.

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Questions …

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