REINHOLD ENVIRONMENTAL Ltd.

2011 APC Round Table & Expo Presentation

July 11-12, 2011, in Cleveland, OH / Hosted by FirstEnergy

An Integrated Approach for Meeting the Proposed Mercury Regulations

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Proposed Mercury Regulation

TABLE 10. EMISSION LIMITATIONS FOR COAL-FIRED AND SOLID OIL-DERIVED FUEL-FIRED EGUS

Subcategory	Total particulate matter	Hydrogen chloride	Mercury
Existing coal-fired unit designed for coal $\geq$ 8,300 Btu/lb	0.030 lb/MMBtu (0.30 lb/MWh)	0.0020 lb/MMBtu (0.020 lb/MWh)	1.0 lb/TBtu (0.0008 lb/GWh)
Existing coal-fired unit designed for coal < 8,300 Btu/lb	0.030 lb/MMBtu (0.30 lb/MWh)	0.0020 lb/MMBtu (0.020 lb/MWh)	11.0 lb/TBtu (0.20 lb/GWh) 4.0 lb/TBtu* (0.040 lb/GWh*)
Existing - IGCC	0.050 lb/MMBtu (0.30 lb/MWh)	0.00050 lb/MMBtu (0.0030 lb/MWh)	3.0 lb/TBtu (0.020 lb/GWh)

Note: 1.0 lb/Tbtu ≈ 1.5 µg/Nm^3 (dry, 3% O_2)

www.**epa**.gov/**air**quality/powerplant**toxics**/pdfs/proposal.pdf

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 60 and 63

[EPA-HQ-OAR-2009-0234; EPA-HQ-OAR-2011-0044, FRL-9148-5]

RIN 2060-AP52

National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-fired Electric Utility Steam Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units

Uncontrolled Mercury Emissions (lb/Tbtu)

based on coal Btu and Hg content – assumes no native removal

Coal Btu/lb (dry basis) \ Coal Mercury Content (ppmw, dry)	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30
14,000	1.4	2.9	4.3	5.7	7.1	8.6	10.0	11.4	12.9	14.3	15.7	17.1	18.6	20.0	21.4
13,500	1.5	3.0	4.4	5.9	7.4	8.9	10.4	11.9	13.3	14.8	16.3	17.8	19.3	20.7	22.2
13,000	1.5	3.1	4.6	6.2	7.7	9.2	10.8	12.3	13.8	15.4	16.9	18.5	20.0	21.5	23.1
12,500	1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.8	14.4	16.0	17.6	19.2	20.8	22.4	24.0
12,000	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13.3	15.0	16.7	18.3	20.0	21.7	23.3	25.0
11,500	1.7	3.5	5.2	7.0	8.7	10.4	12.2	13.9	15.7	17.4	19.1	20.9	22.6	24.3	26.1
11,000	1.8	3.6	5.5	7.3	9.1	10.9	12.7	14.5	16.4	18.2	20.0	21.8	23.6	25.5	27.3
10,500	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.2	17.1	19.0	21.0	22.9	24.8	26.7	28.6
10,000	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0
9,500	2.1	4.2	6.3	8.4	10.5	12.6	14.7	16.8	18.9	21.1	23.2	25.3	27.4	29.5	31.6
9,000	2.2	4.4	6.7	8.9	11.1	13.3	15.6	17.8	20.0	22.2	24.4	26.7	28.9	31.1	33.3
8,500	2.4	4.7	7.1	9.4	11.8	14.1	16.5	18.8	21.2	23.5	25.9	28.2	30.6	32.9	35.3
8,000	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5

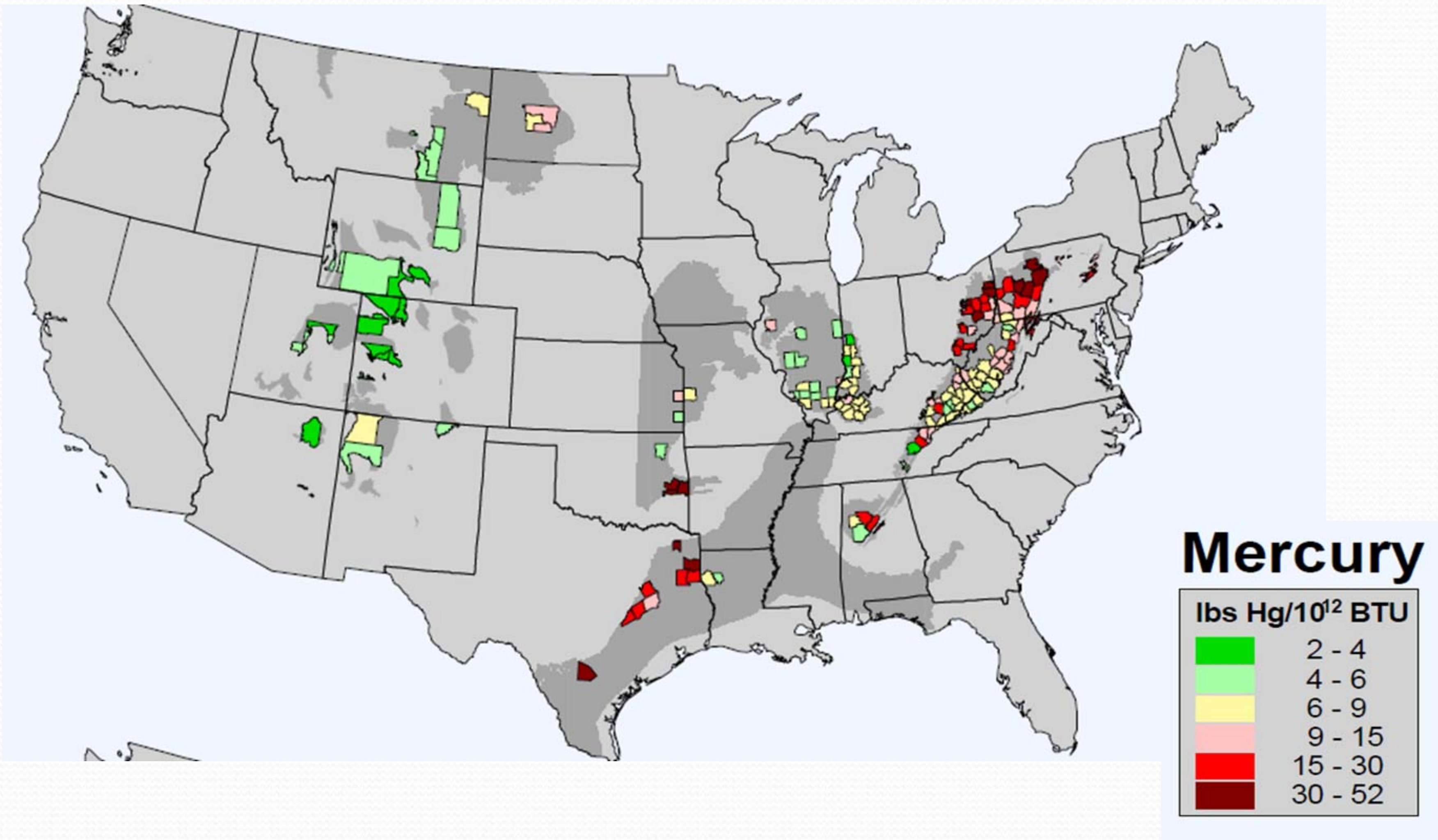
Required Mercury Removal (%)

to meet 1 lb/Tbtu - based on coal Btu and Hg content

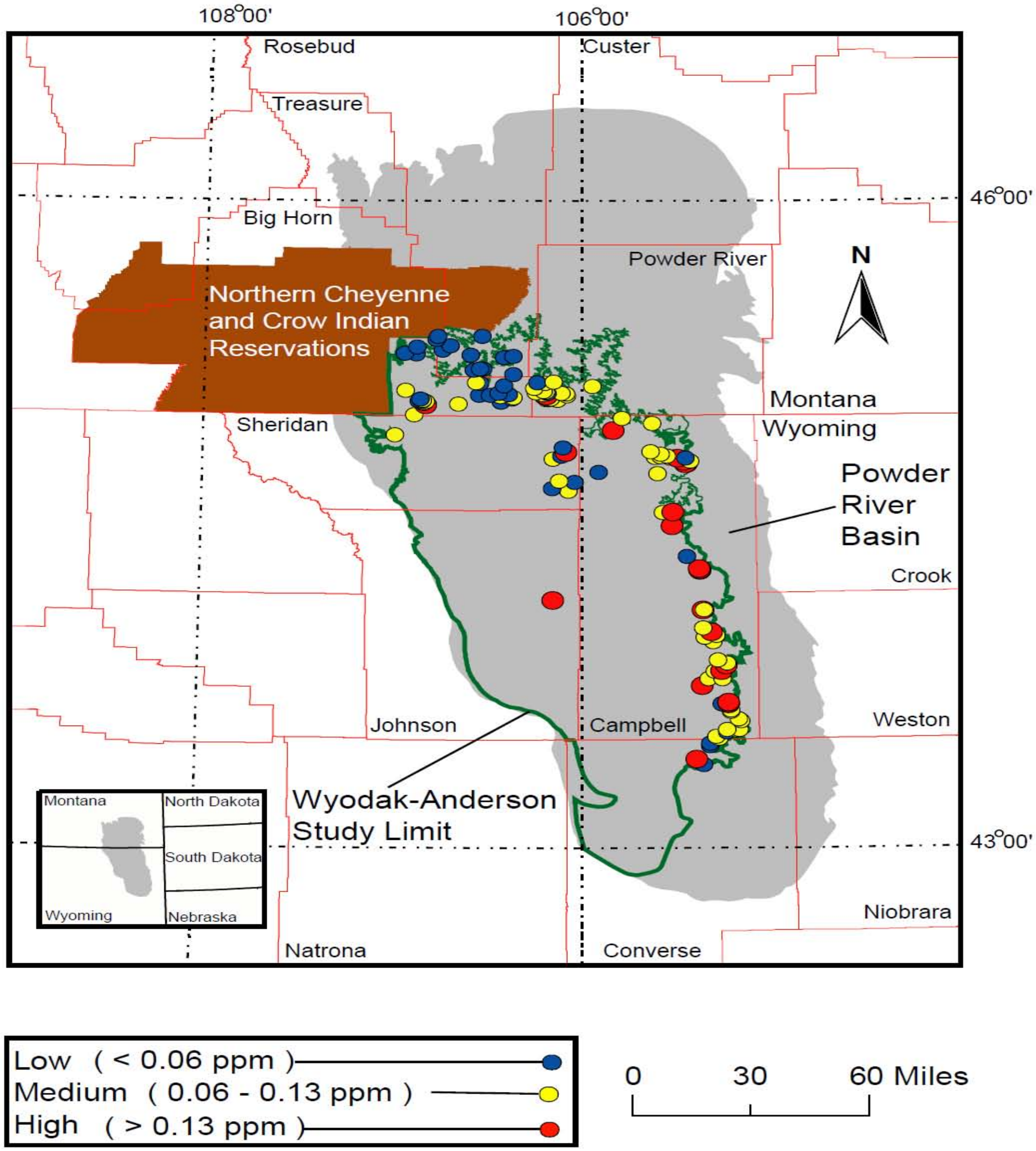
Coal Btu/lb (dry basis)	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30
14,000	30	65	77	83	86	88	90	91	92	93	94	94	95	95	95
13,500	33	66	78	83	87	89	90	92	93	93	94	94	95	95	96
13,000	35	68	78	84	87	89	91	92	93	94	94	95	95	95	96
12,500	38	69	79	84	88	90	91	92	93	94	94	95	95	96	96
12,000	40	70	80	85	88	90	91	93	93	94	95	95	95	96	96
11,500	43	71	81	86	89	90	92	93	94	94	95	95	96	96	96
11,000	45	73	82	86	89	91	92	93	94	95	95	95	96	96	96
10,500	48	74	83	87	90	91	93	93	94	95	95	96	96	96	97
10,000	50	75	83	88	90	92	93	94	94	95	95	96	96	96	97
9,500	53	76	84	88	91	92	93	94	95	95	96	96	96	97	97
9,000	55	78	85	89	91	93	94	94	95	96	96	96	97	97	97
8,500	58	79	86	89	92	93	94	95	95	96	96	96	97	97	97
8,000	60	80	87	90	92	93	94	95	96	96	96	97	97	97	97

Coal Mercury Content (ppmw, dry)

Mercury Concentrations for U.S. Coals



PRB Mercury Map Detail



Average for PRB Coals

(Dry basis)

Mercury = 0.13 ppmw

HHV = 11,370 Btu/lb

COAL QUALITY AND GEOCHEMISTRY, POWDER RIVER BASIN, WYOMING AND MONTANA

By G.D. Stricker and M.S. Ellis

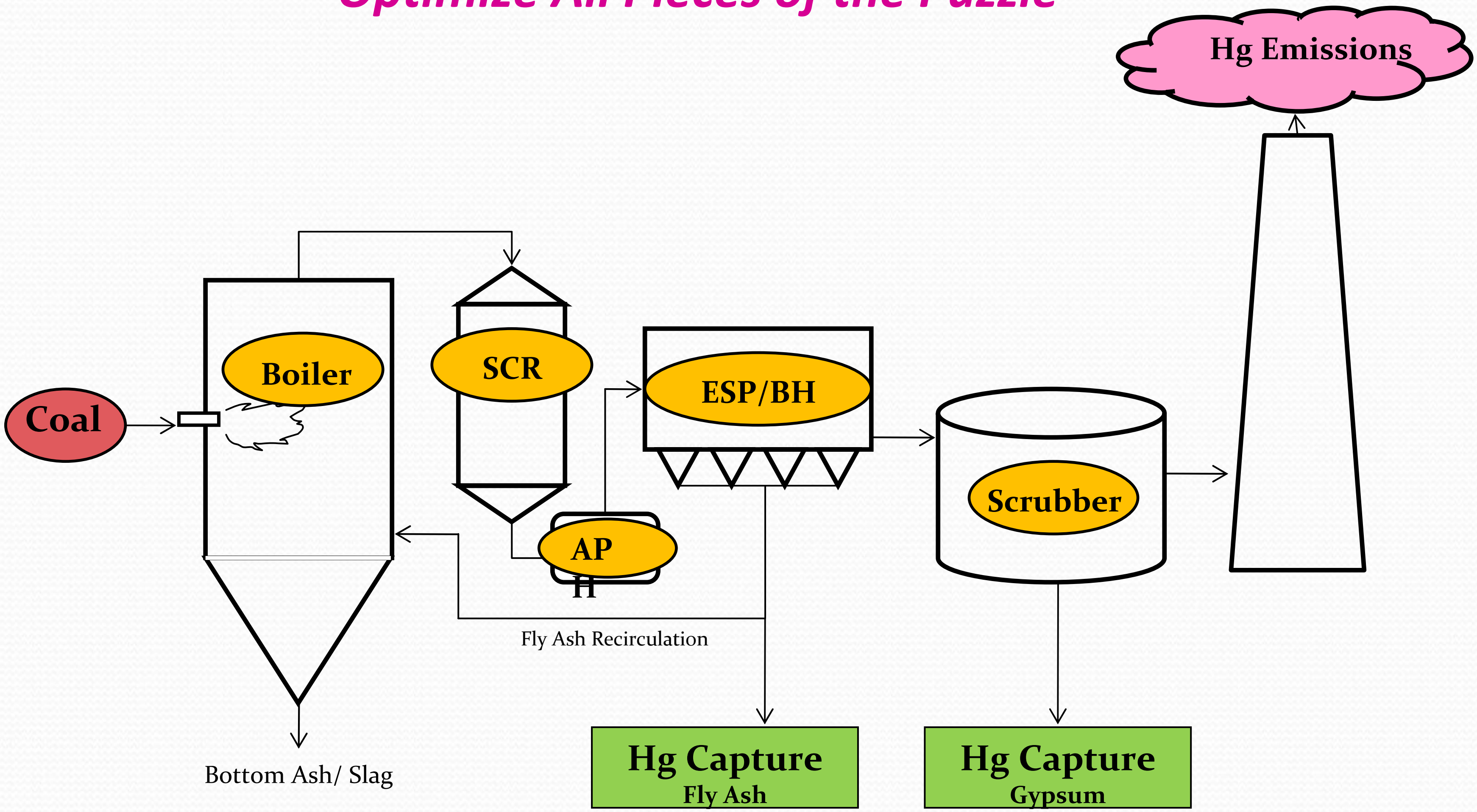
in U.S. Geological Survey Professional Paper 1625-A

CO-BENEFIT CAPTURE

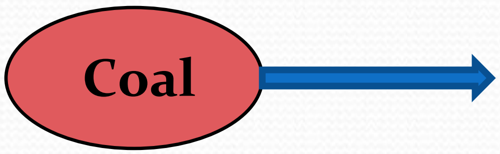
NO DEDICATED MERCURY CONTROLS

MAXIMIZING MERCURY OXIDATION CRITICAL TO CO-BENEFIT CAPTURE

Optimize All Pieces of the Puzzle



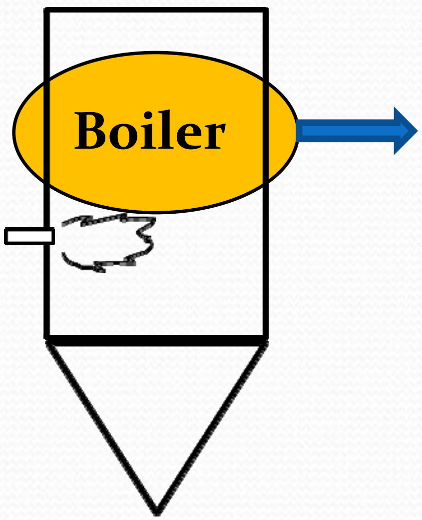
Puzzle Piece: COAL



- **Fuel controls the mercury input and removal required.**
- **Low heating value effectively increases mercury removal requirement for constant mercury content on ppmw basis.**
- **Coal halogen level may be more important than the coal mercury content – but both must be considered.**
- **Higher sulfur coal will result in more generally result in more SO3 which may impact mercury adsorption.**
- **Pay attention to coal purchasing arrangements and specifications.**

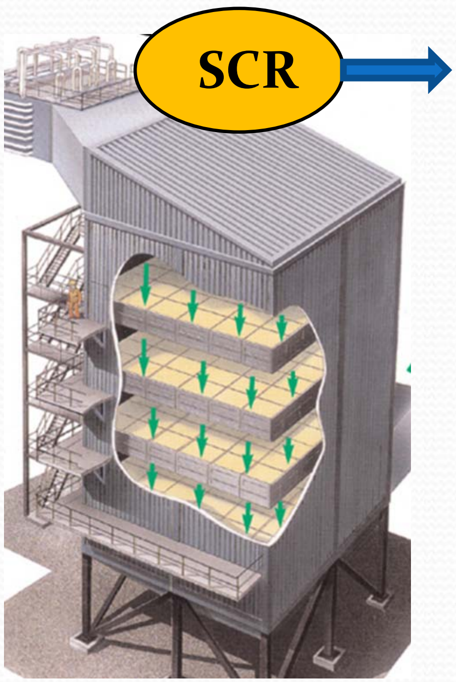
- **Best Coal: high halogen, high Btu, low mercury**
- **Worst Coal: low halogen, low Btu, high mercury**

Puzzle Piece: BOILER



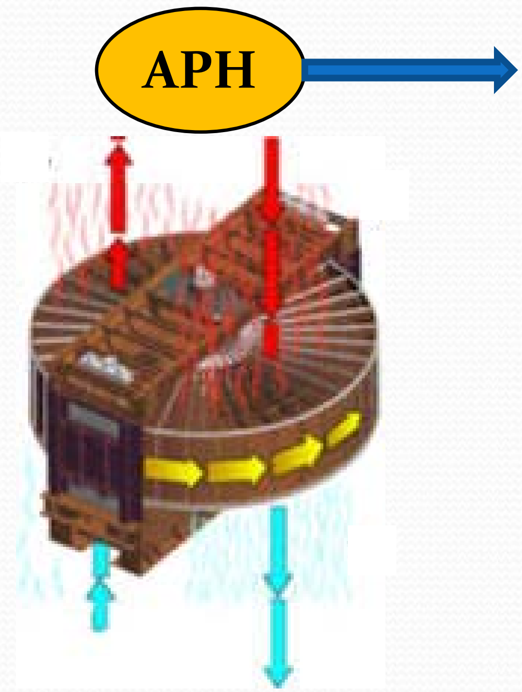
- **Boiler conditions favor elemental mercury – most reactions of interest take place as flue gas cools through economizer and other downstream devices.**
- **Boiler operation affects SO3 formation which in turn potentially affects particulate and mercury capture.**
- **The boiler controls LOI which will affect native mercury capture – higher LOI generally good for mercury capture.**
- **Boiler will affect NOx and O2 which may in turn affect SCR mercury oxidation**
- **Boiler operation will likely affect SCR operating temperature, which in turn affects mercury oxidation – LOWERED ECONOMIZER OUTLET TEMPERATURES WILL GENERALLY HELP WITH MERCURY OXIDATION AND CAPTURE**

Puzzle Piece: SCR



- **Lower temperature operation favors mercury oxidation.**
- **Minimize ammonia slip to improve mercury oxidation: maintain reactor potential, avoid mal-distributions, fouling, etc. However, how does slip affect mercury capture?**
- **Higher reactor potential margins will maximize mercury oxidation: More catalyst = more mercury oxidation, all other factors being equal.**
- **Some evidence that high SO2 conversion improves mercury oxidation, but high SO3 may adversely affect mercury capture. Better understanding of catalyst trade-offs needed.**
- **Mercury oxidation will decline with catalyst age – implement good catalyst management plans.**
- **Conventional SCR catalysts need halogens !**
- **Hope for continued improvement in catalyst as well as advanced catalyst designs. More research needed.**

Puzzle Piece: AIR PREHEATER



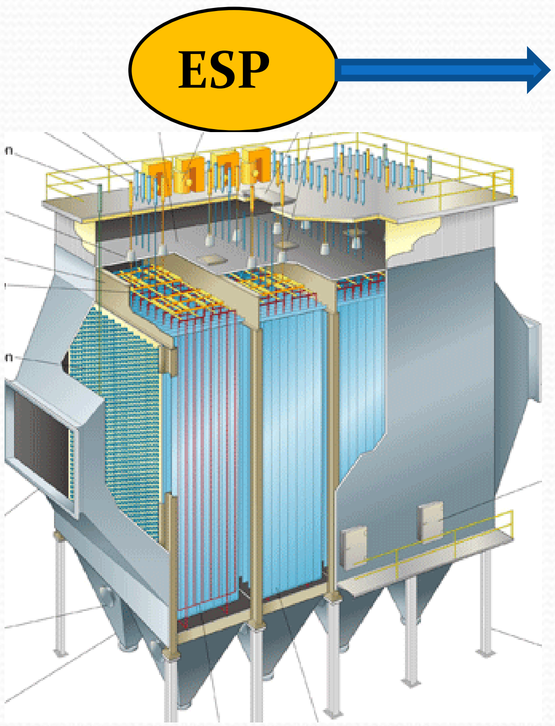
- **Mercury speciation of real interest is at the air preheater outlet – this is the best indicator of speciation entering devices that actually capture the mercury.**

- **Data show that mercury oxidation continues to occur as flue gas is cooled through air preheater – SPECIATION IS NEVER STATIC !**

- **Lowered APH outlet temperature generally good for all downstream devices in terms of mercury capture.**

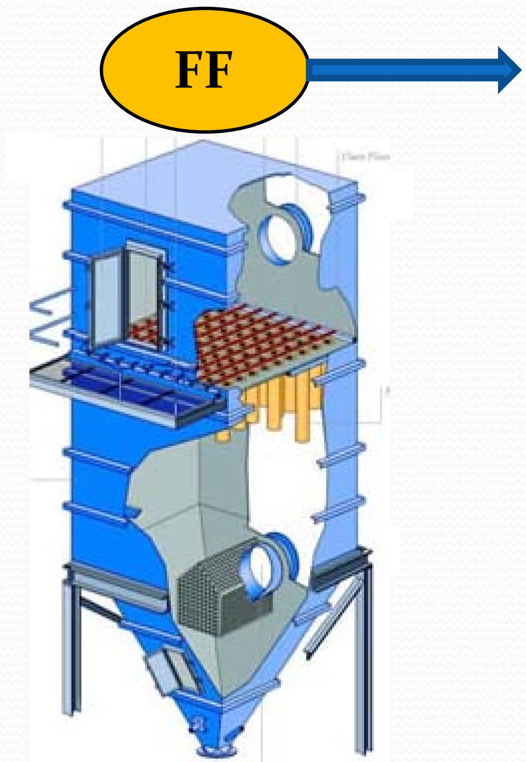
- **More work needed to understand APH impacts and ways that APH operation can be optimized for mercury oxidation and capture.**

Puzzle Piece: ESP



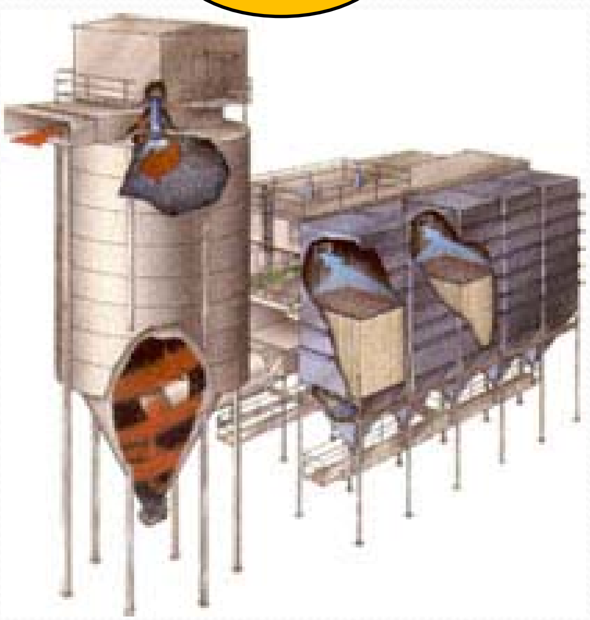
- **Optimize ESP to do its job – remove particulate !**
- **Reminder: Coal characteristics will affect ash resistivity, humidity, SO2/SO3, etc., which will all in turn affect particulate and mercury removal.**
- **Fine particulate may demonstrate enrichment in terms of mercury capture, so improvements aimed specifically at capturing fines may be especially helpful.**
- **Be careful of the impacts of improved particulate capture on mercury removal: SO3 conditioning may help particulate removal but hurt mercury removal, due to interference with active mercury sorption sites. Impact of ammonia conditioning ?**
- **Optimize rapping to minimize re-entrainment.**
- **Novel ideas for improving ESP capture ?**
  Example: Ancillary cooling/humidification
- **If scrubber is located downstream, focus may be minimizing elemental mercury breakthrough, rather than total mercury removal.**

Puzzle Piece: Fabric Filter



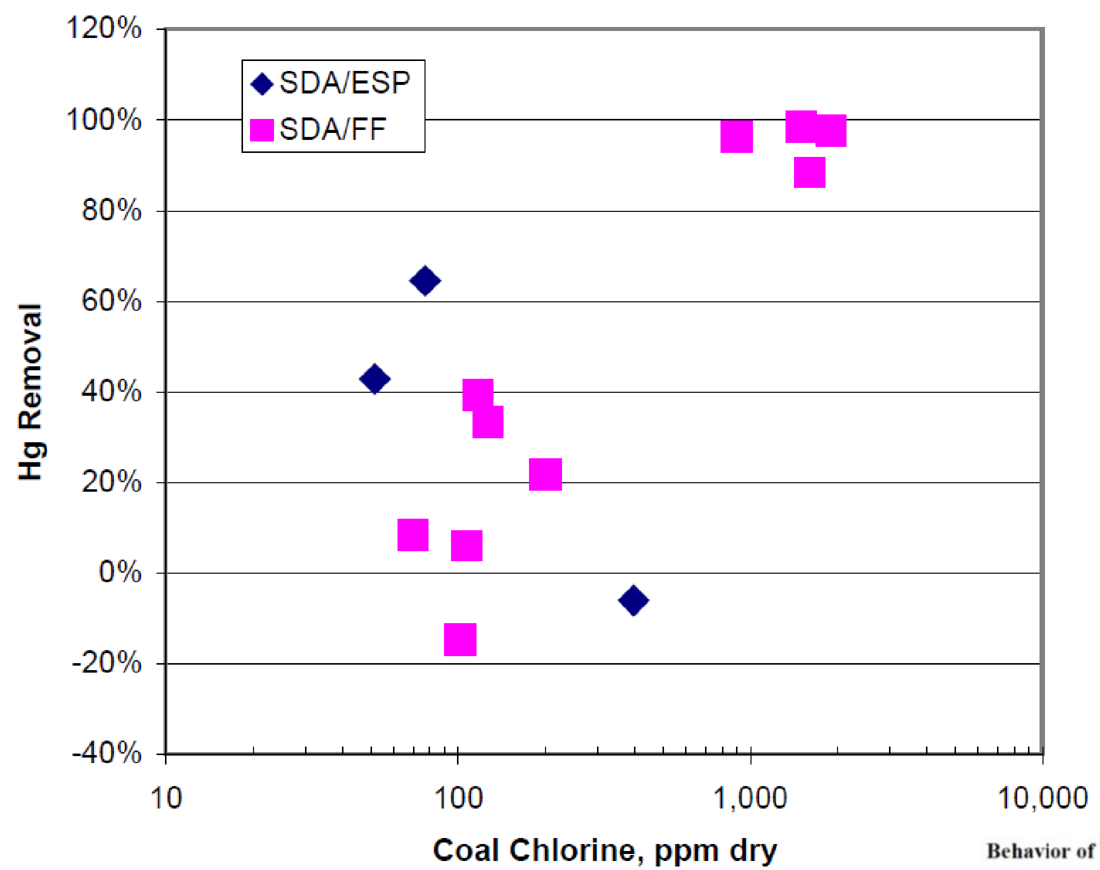
- Fabric filter generally better at removing mercury due to improved particulate capture and improved gas/solid contacting/mass transfer.
- Most parameters affecting ESP mercury capture will similarly affect fabric filters, at least qualitatively.
- Blowback/cleaning operations critical to minimizing re-entrainment and mercury re-emission.
- Fabric filter mercury capture may be particularly to sensitive to LOI, SO3, ash minerals etc. as compared to ESP.
- Fly ash acts as a “native” sorbent, so ash parameters, including PSD, surface area, and ash minerals will affect mercury capture.
- Presence of downstream scrubber may affect the scenario for optimized mercury removal – if scrubber present, the focus may be minimizing elemental mercury breakthrough, rather than total mercury removal.

Puzzle Piece: SDA + Fabric Filter



- **Addition of SO2 sorbent impacts overall mercury removal as compared to FF alone.**
- **Longer overall residence times, higher mass loading, coupled with temperature quench generally improves capture.**
- **Very high removals noted for high-halogen flue gas – removal generally poor for PRBs due to high elemental proportion.**
- **Any action that improves mercury oxidation entering the SDA/FF will generally improve capture.**
- **Optimize FF operation for particulate removal, minimize re-entrainment, etc.**
- **Lack of downstream scrubber means that SDA/FF must maximize capture, not just minimize elemental mercury breakthrough.**

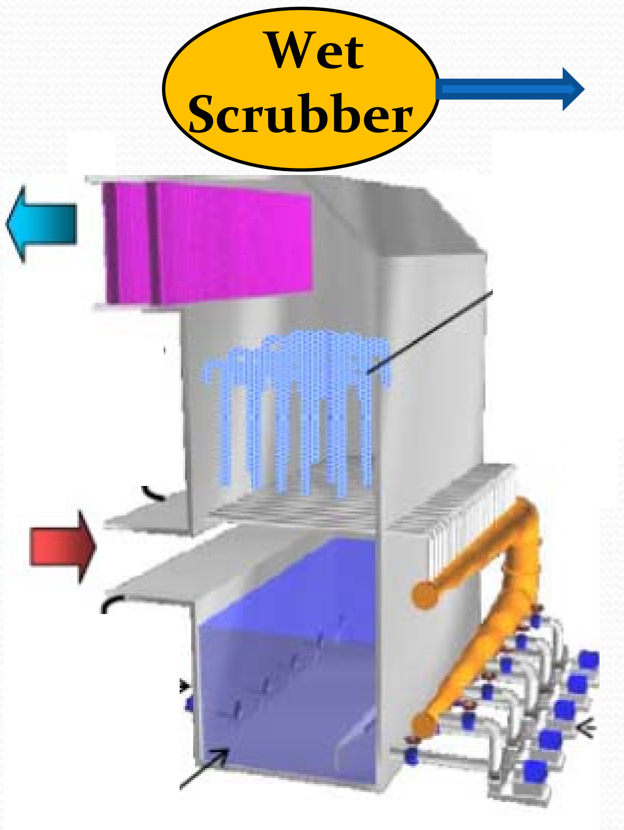
Example Mercury Removal Results for SDA-FF/ESP Configurations



Behavior of Mercury in Air Pollution Control Devices on Coal-Fired Utility Boilers[1]

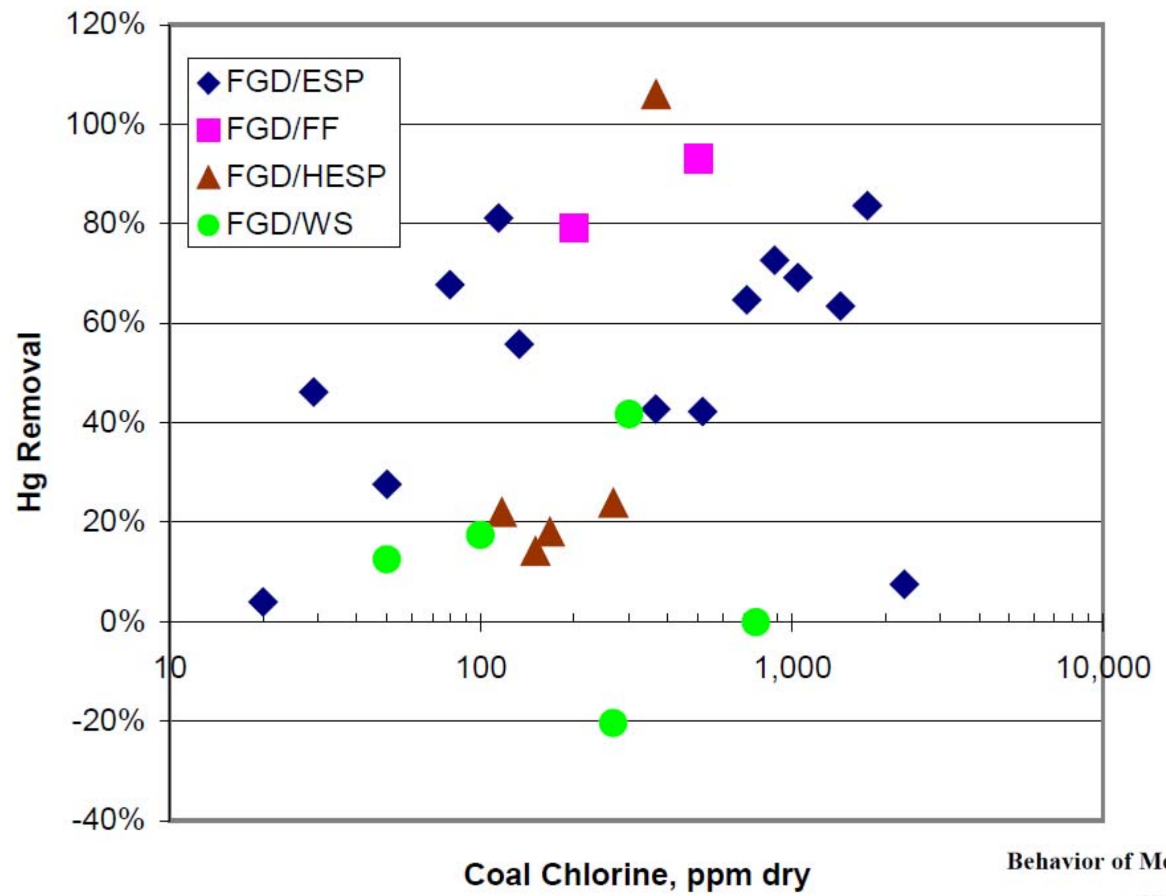
Constance L. Senior
Reaction Engineering International
Salt Lake City, Utah 84101

Puzzle Piece: Wet Scrubber



- **Primarily only removes oxidized mercury.**
- **Everything upstream affecting mercury speciation in turn will affect scrubber capture.**
- **Re-emission of elemental mercury a problem – very little margin for re-emission when 90%+ removal needed.**
- **Various operational conditions affect mercury capture and re-emission – dependent on specific scrubber design.**
- **Scrubber additives have the potential to maximize oxidized mercury capture, and minimize elemental mercury re-emission.**

Example Mercury Removal Based on Wet-Scrubber Configuration



Behavior of Mercury in Air Pollution Control Devices on Coal-Fired Utility Boilers[1]

Constance L. Senior
Reaction Engineering International
Salt Lake City, Utah 84101

DEDICATED CONTROLS

1. **Halogen Addition**

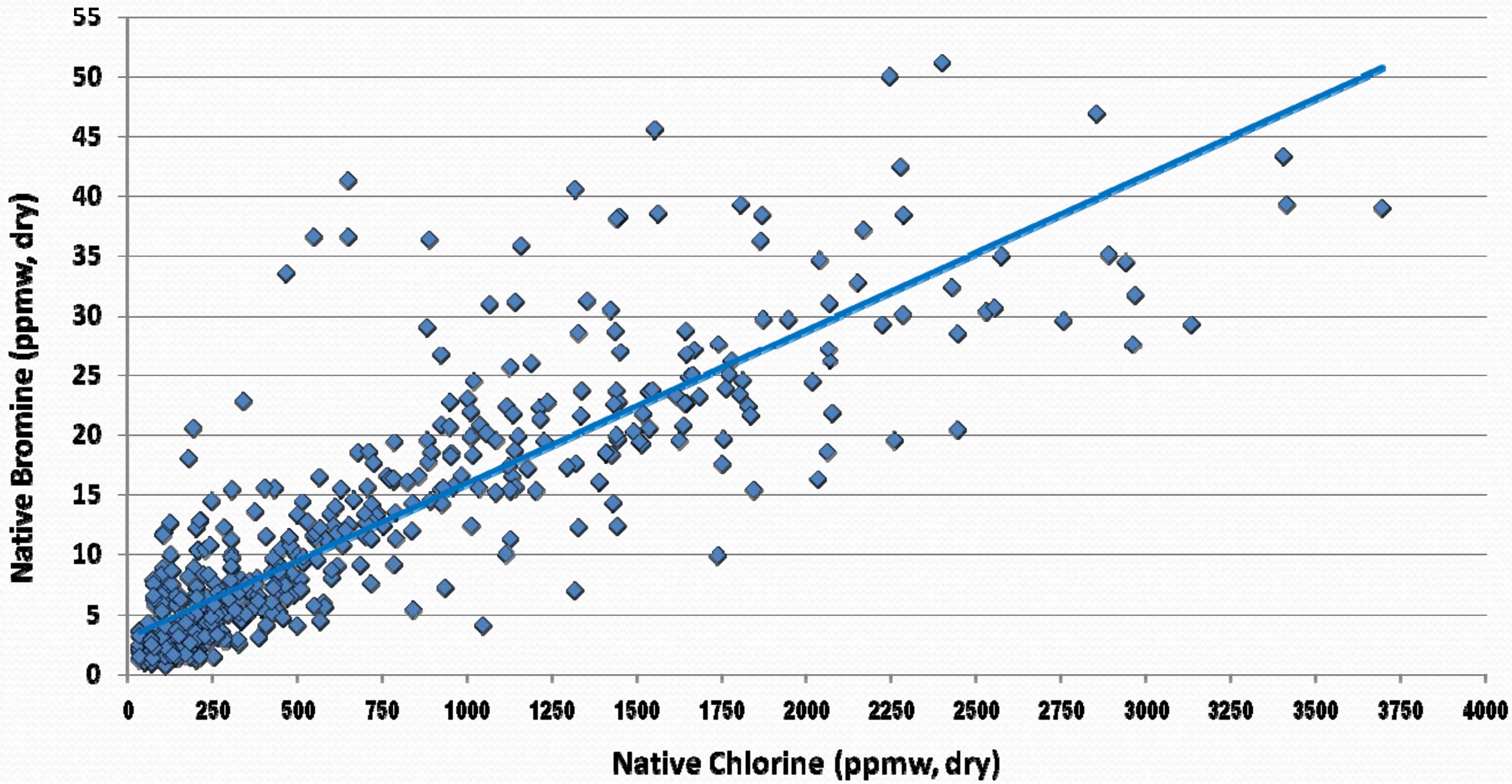
2. **Sorbent Systems**

Halogen Addition

- **Bromine via Coal Additives**
- **Chlorine via Coal Additives**
- **Chlorine via Fuel Switching**

Bromine and Chlorine Inter-Related

Coals low in Chlorine will also generally be low in Bromine



Coal Composition Based on USGS Data

Bromine Has Synergistic Effect

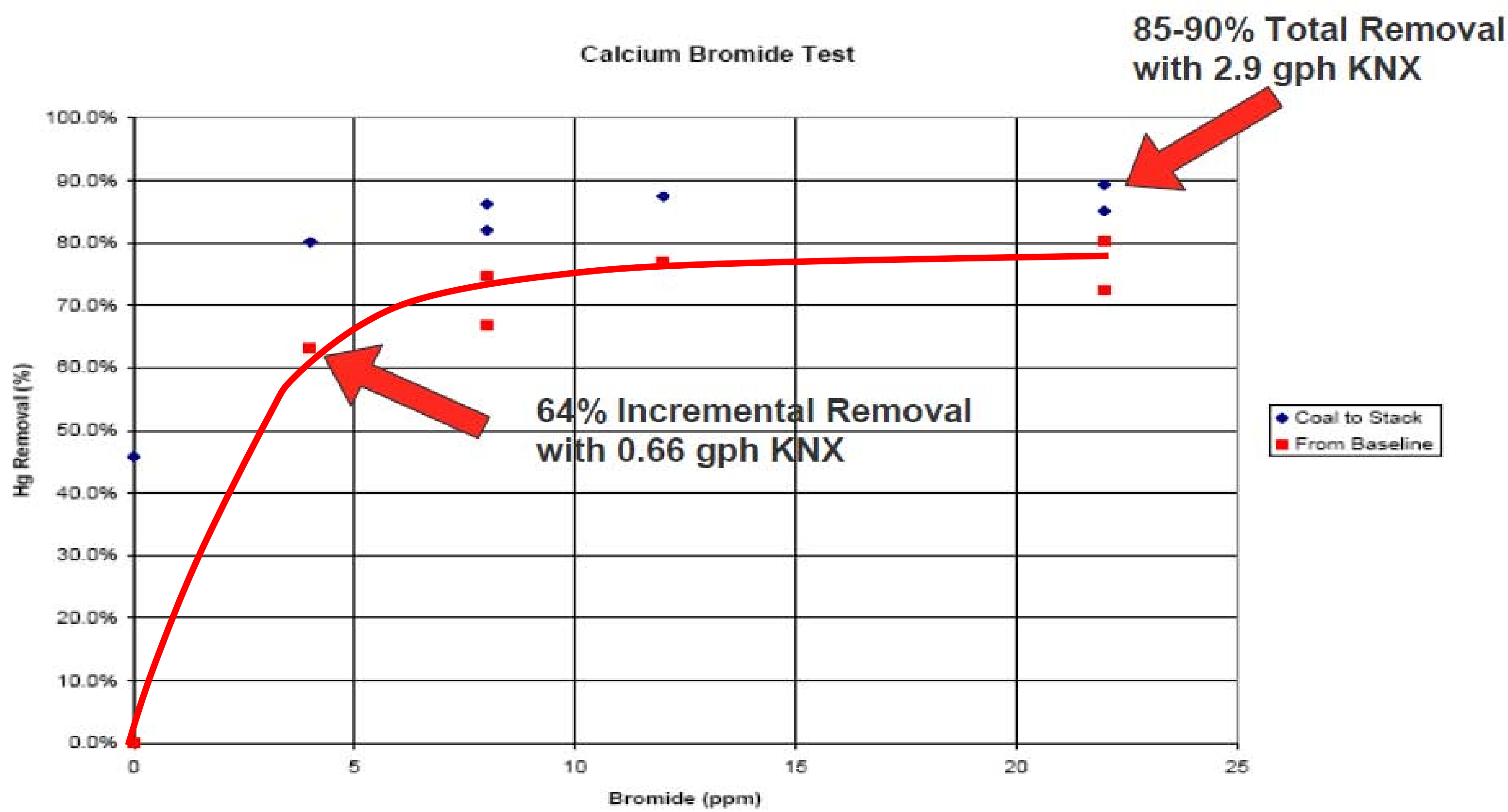
(in some cases)

1. **Improves mercury oxidation in virtually all down-stream equipment.**

2. **Improves the apparent capture of the oxidized mercury.**

Classic Example of Bromine Effect

600 MW PRB/SCR/ESP/WFGD Results



Preliminary data

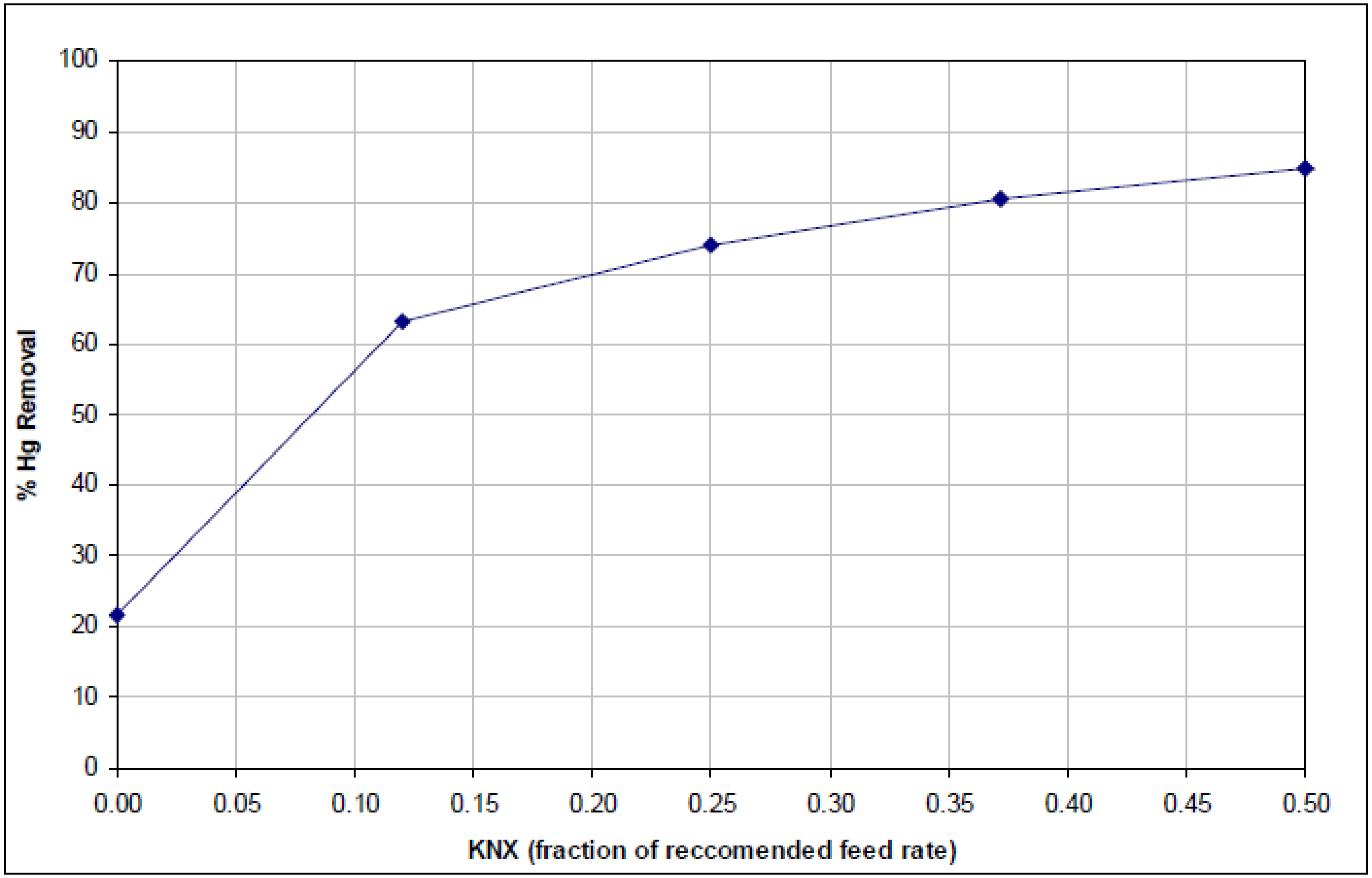
POWER ALSTOM

KNX Technology for mercury control from coal-fired boilers

Michael J. Rini

Environmental Control Systems

Bromine effects on PRB plant with SCR-SDA/FF



Mercury Control at New Generation Western PC Plants

Paper #08-A-169-Mega-AWMA

Jerry Amrhein
ADA Environmental Solutions
8100 SouthPark Way, Unit B
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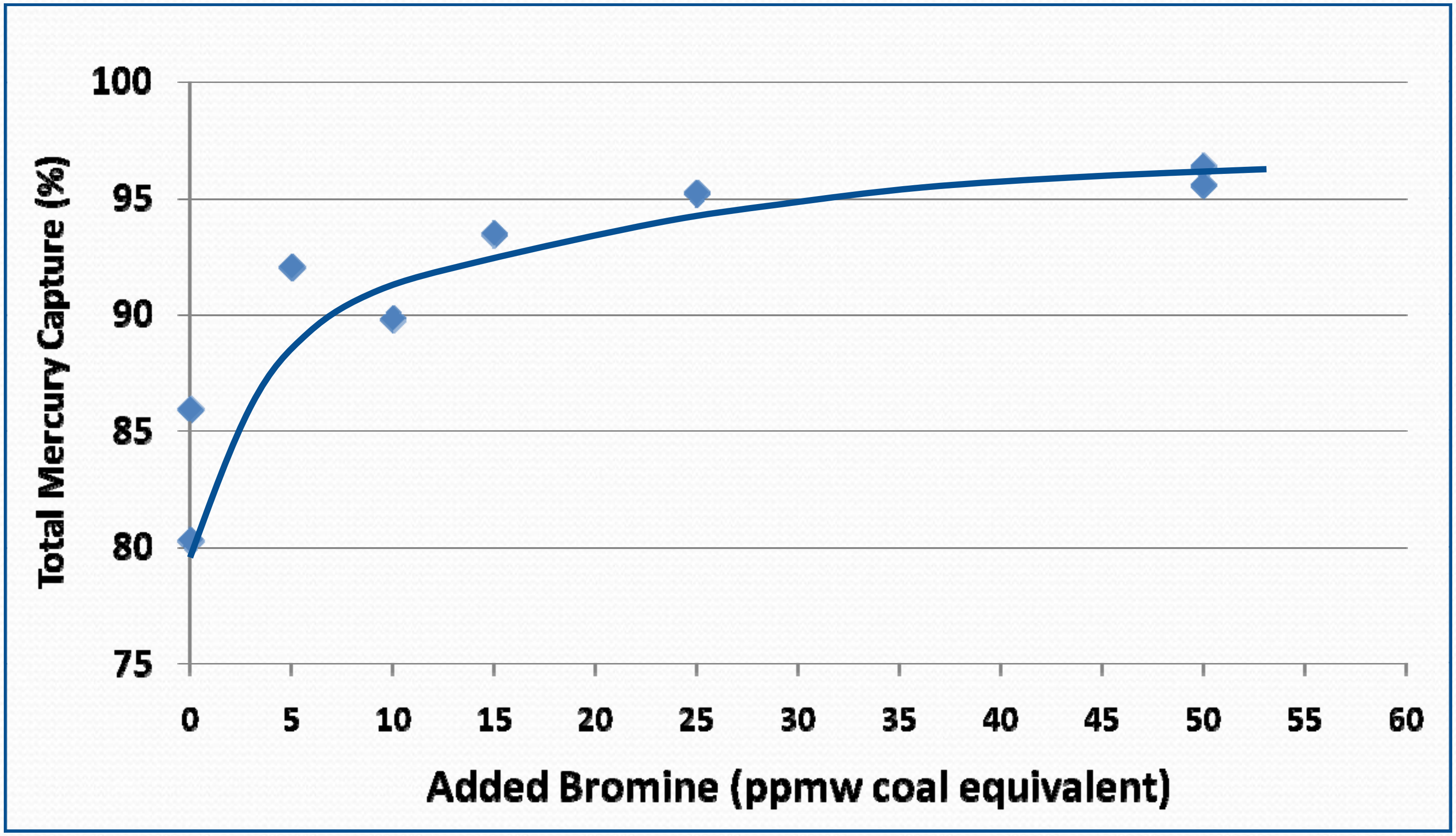
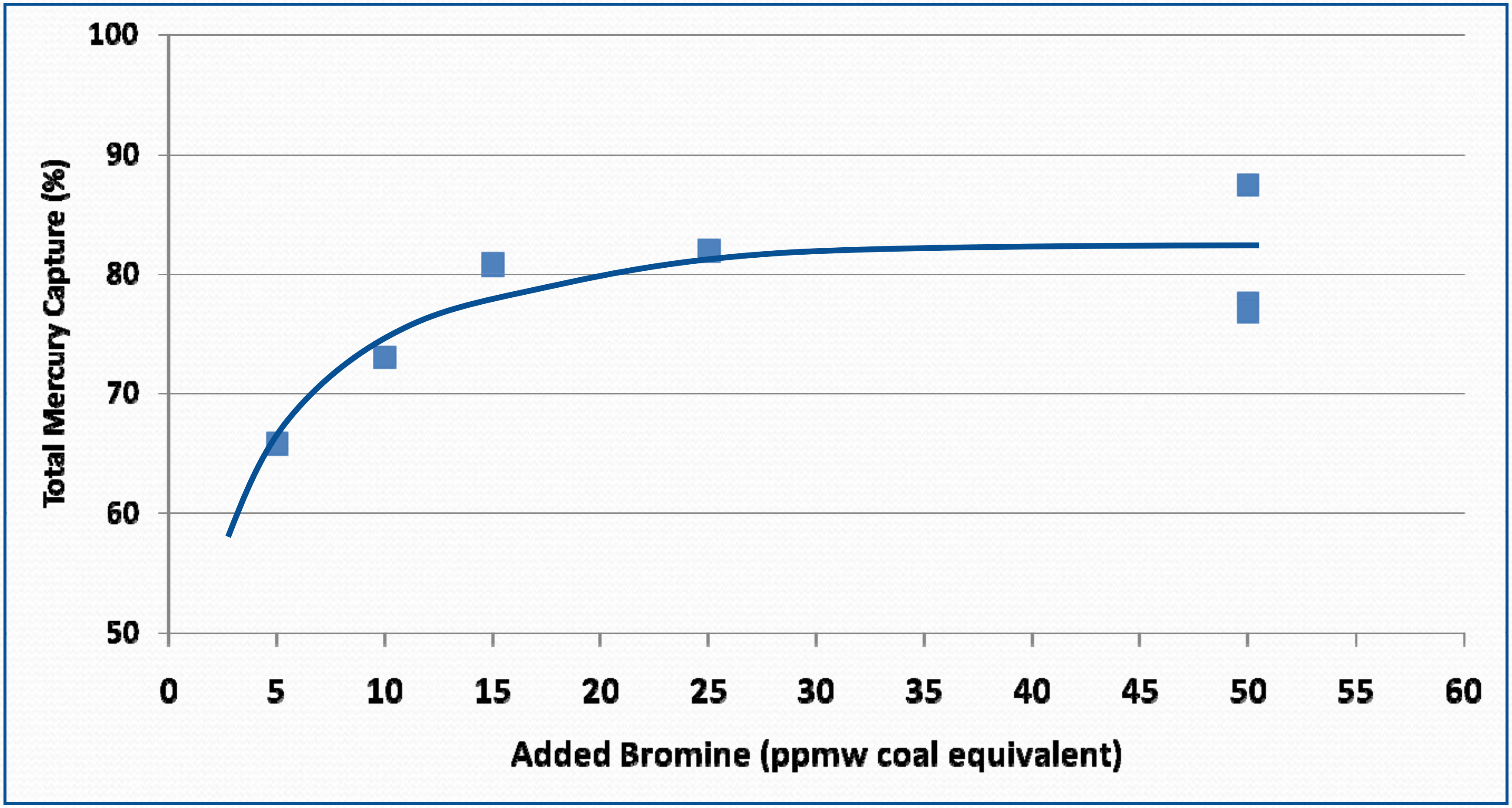
Bromine addition with SCR-Wet Scrubber, on low chlorine eastern bituminous coal



Bromine effect on SCR-ESP Capture with low chlorine eastern bituminous coal

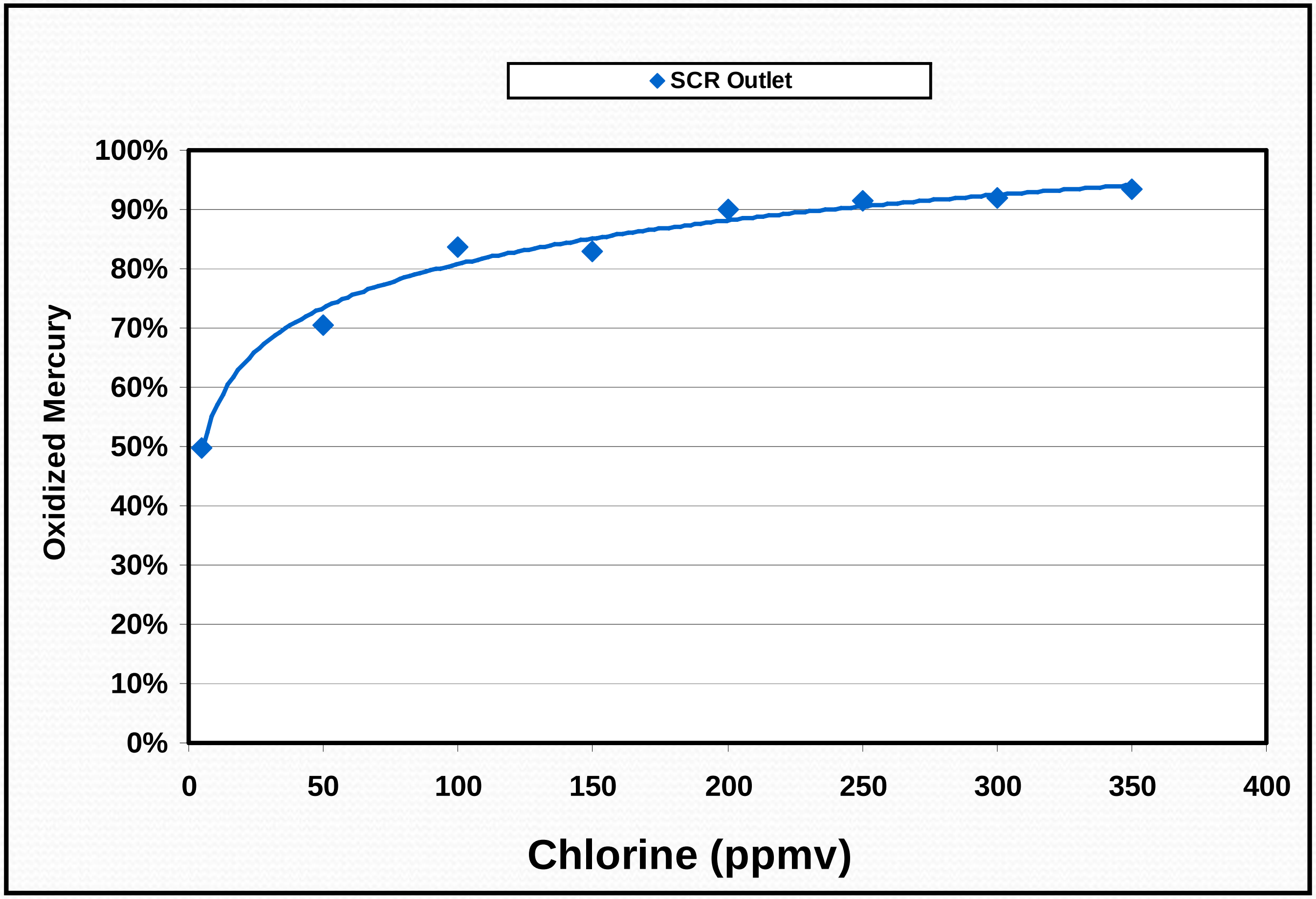


Chlorine Effects

1. Chlorine can have similar effect to bromine, but much more required.

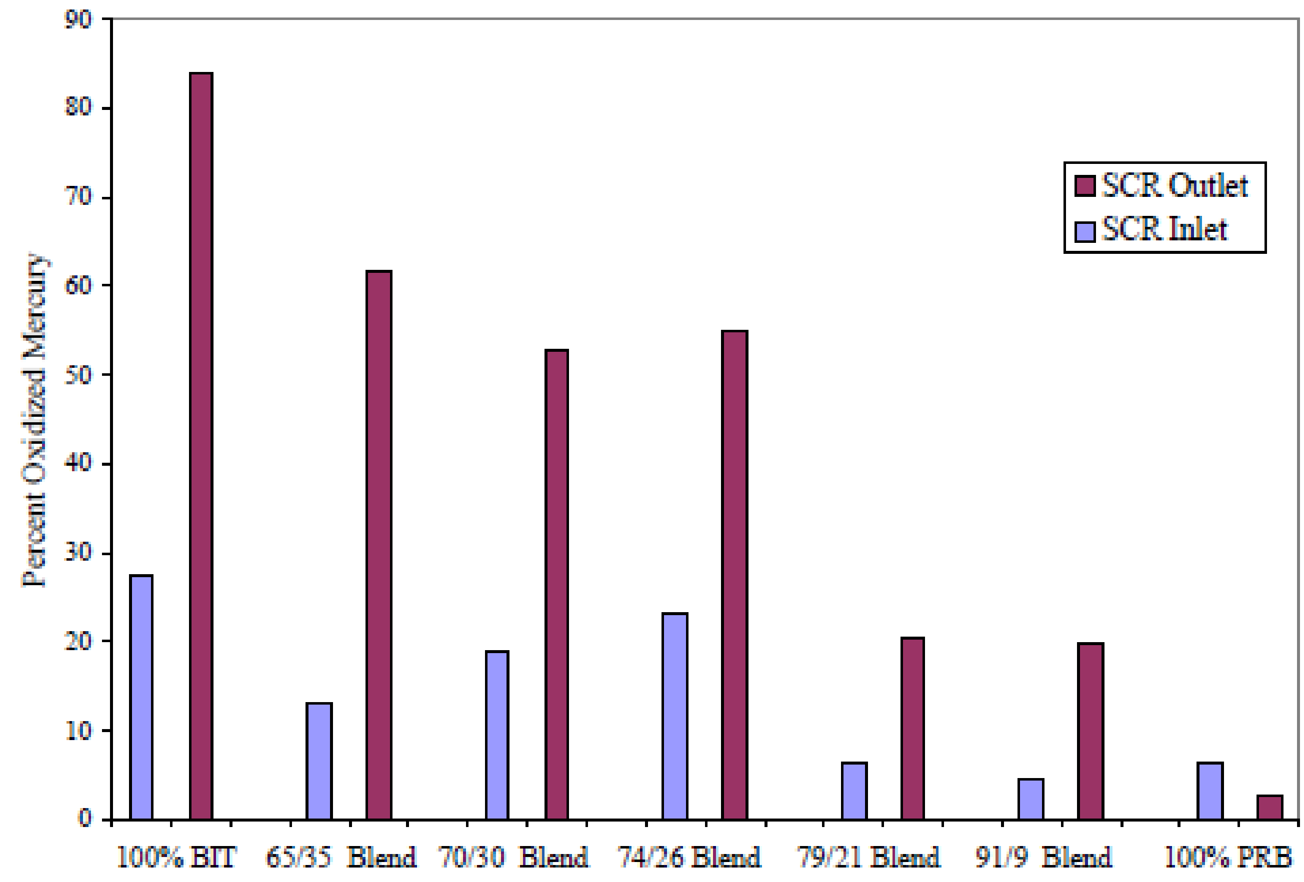
2. Primary effect due to improved mercury oxidation, although synergistic effect may also be present, similar to bromine.

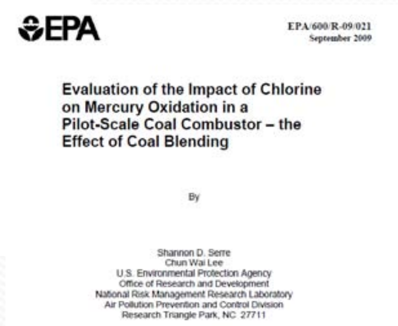
Example Chlorine Addition (as HCl) on SCR Oxidation with low chlorine eastern bituminous fuel



Effect of Fuel Blending (high to low chlorine) on SCR Mercury Oxidation

Remember: fuel blending changes a lot more than chlorine !





EPA

EPA/600/R-09/021
September 2009

Evaluation of the Impact of Chlorine on Mercury Oxidation in a Pilot-Scale Coal Combustor – the Effect of Coal Blending

By

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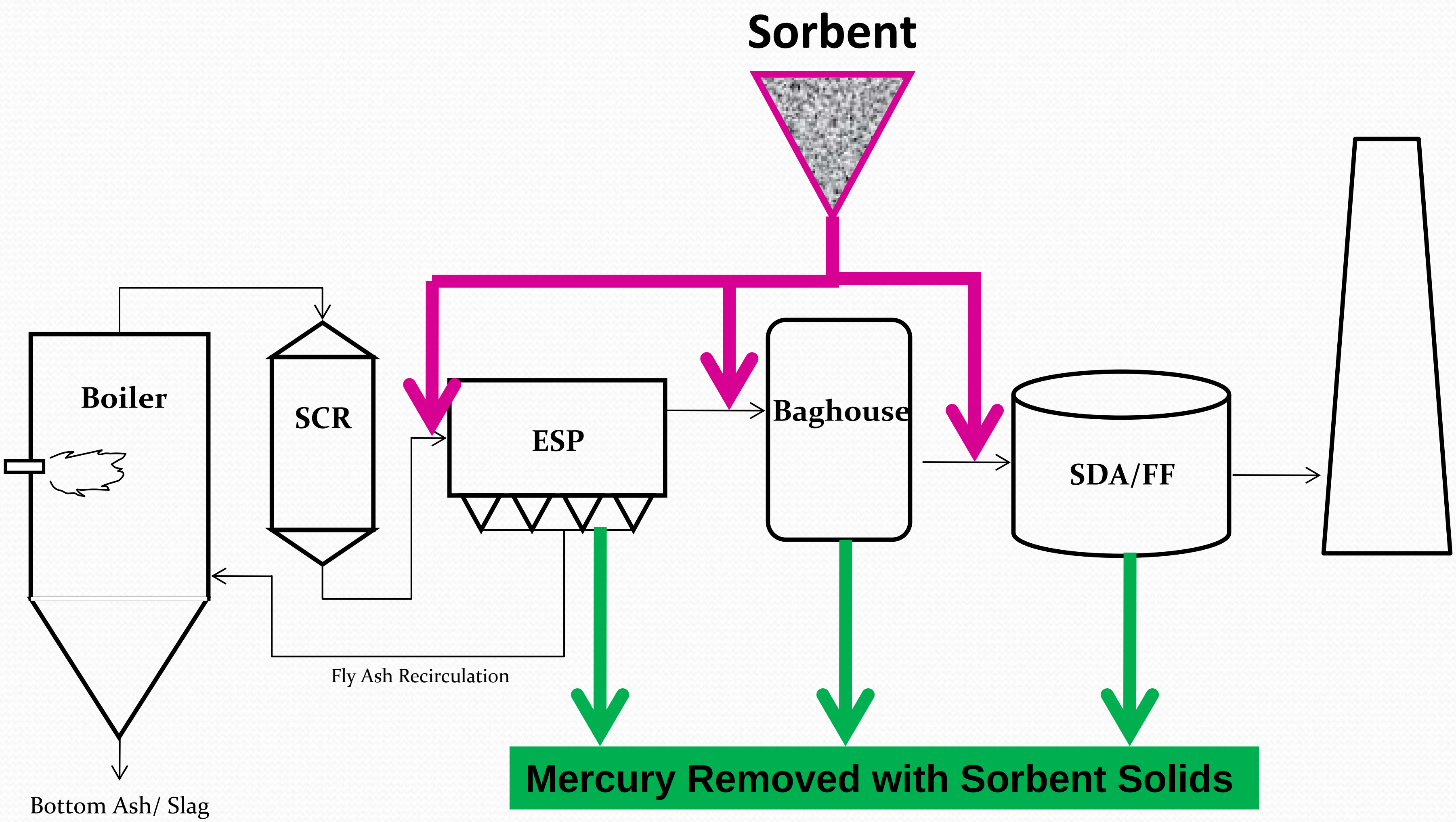
Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
Research Triangle Park, NC 27711

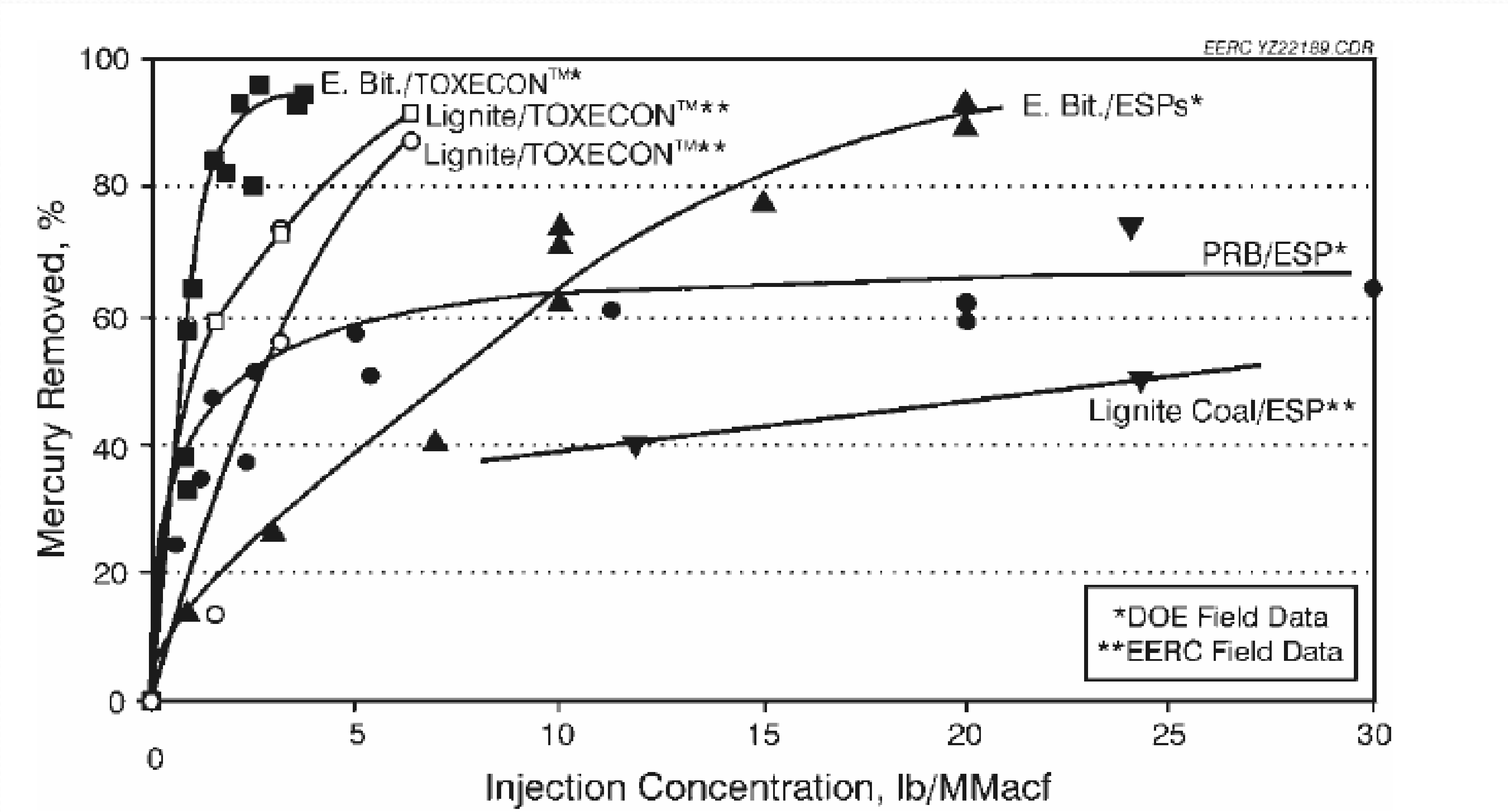
SORBENT INJECTION



Sorbent Efficiency Affected by Many Parameters

- **Sorbent Design: general type, specific chemistry, SA, PSD**
- **Injection Rate**
- **Type of particulate control device and specific design**
- **Mercury speciation**
- **Flue gas halogens (inter-related with speciation)**
- **SO2/SO3**
- **Temperature**
- **Distribution**
- **Residence Time**

Examples of Activated Carbon with various particulate controls

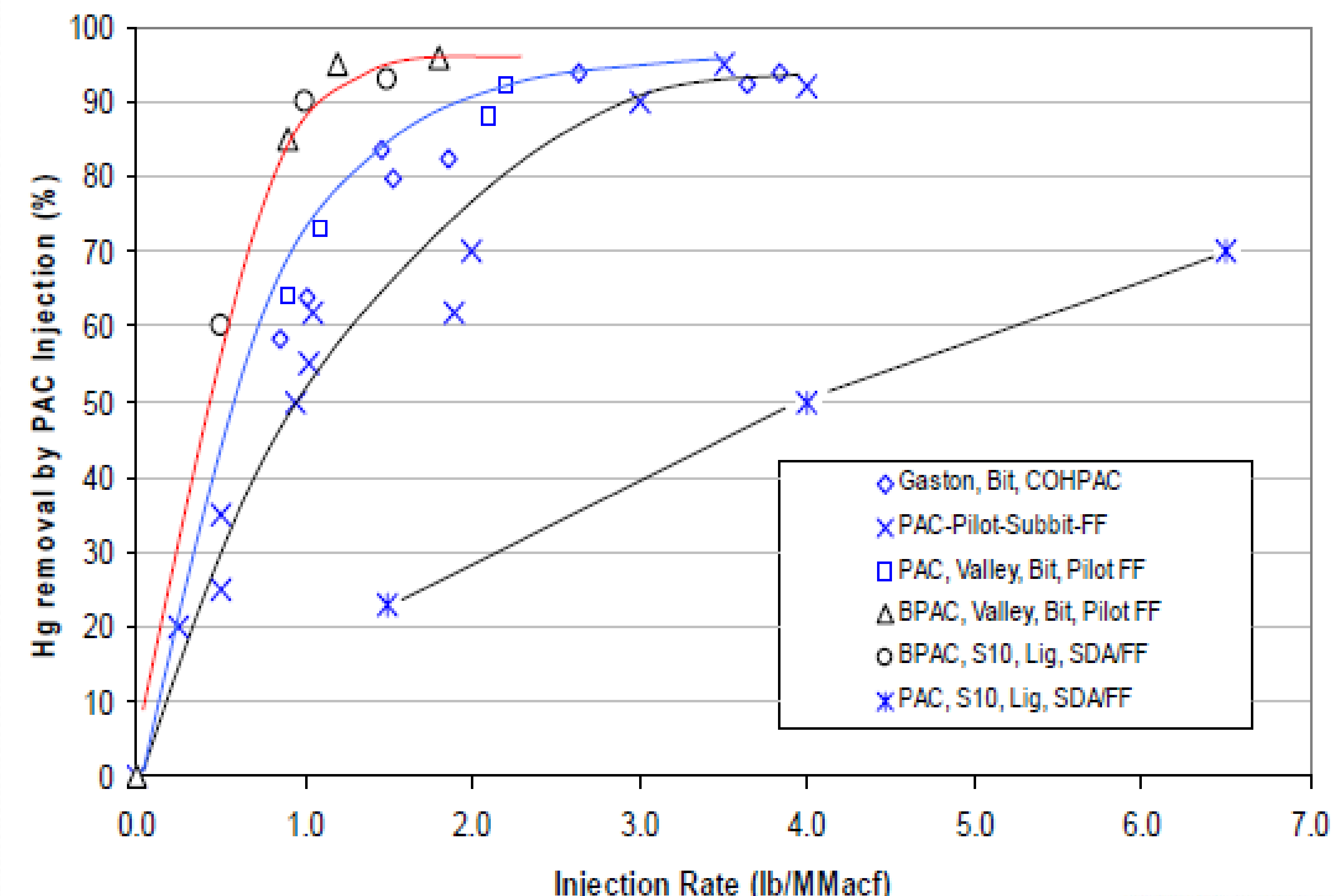


PILOT-SCALE EVALUATION OF ACTIVATED CARBON-BASED MERCURY CONTROL OPTIONS FOR UTILITIES BURNING LIGNITE COAL

Michael J. Holmes, John H. Pavlish, Ye Zhuang,. Steven A. Benson, and Matthew J. Fritze

University of North Dakota Energy & Environmental Research Center, PO Box 9018, Grand Forks, ND 58202-9018

Mercury Capture by Activated Carbon Upstream of FF



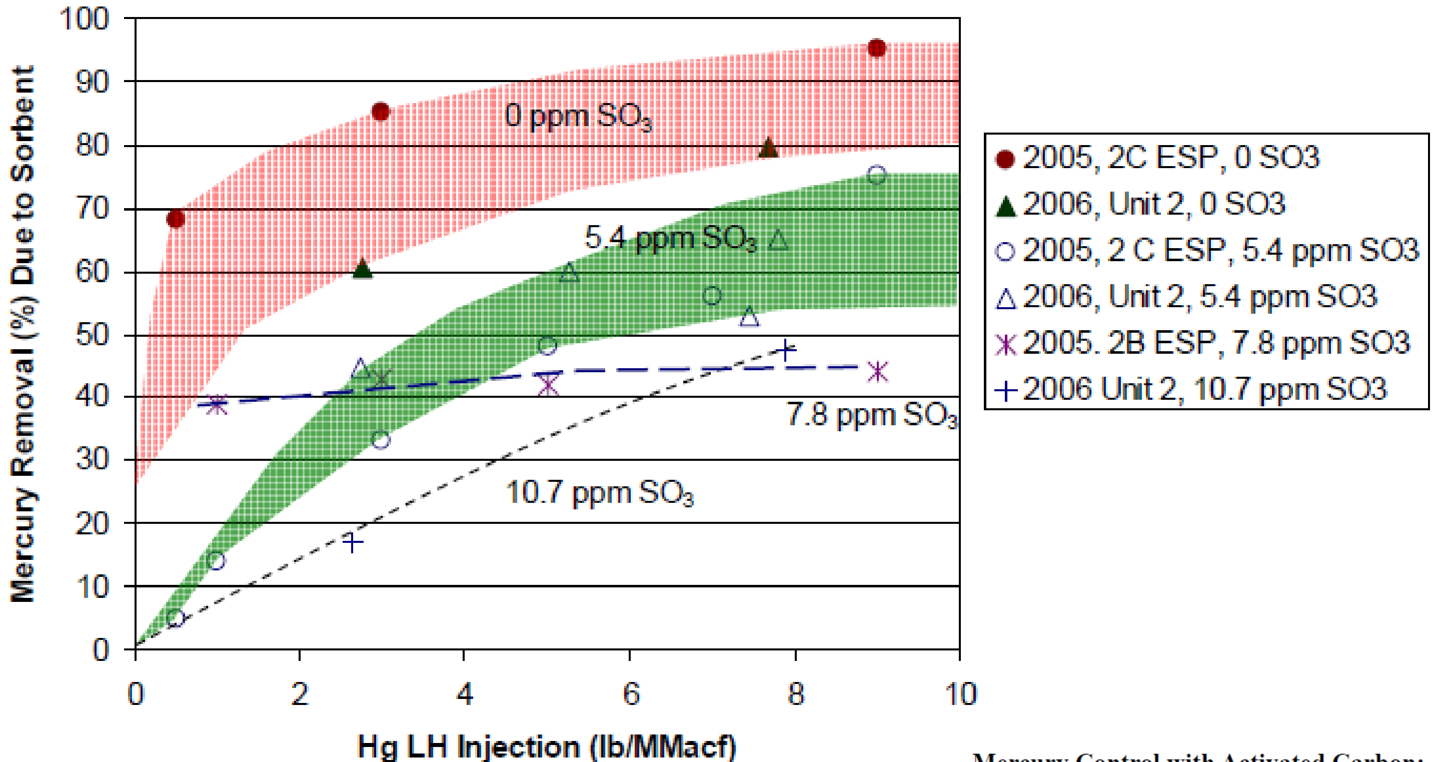
Control of Mercury Emissions from Coal Fired Electric Utility Boilers: An Update

by

Ravi Strivastava
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
Research Triangle Park, NC 27711

Adverse Effect of SO3 on ACI

Figure 7. Summary of mercury removal results with DARCO® Hg-LH.

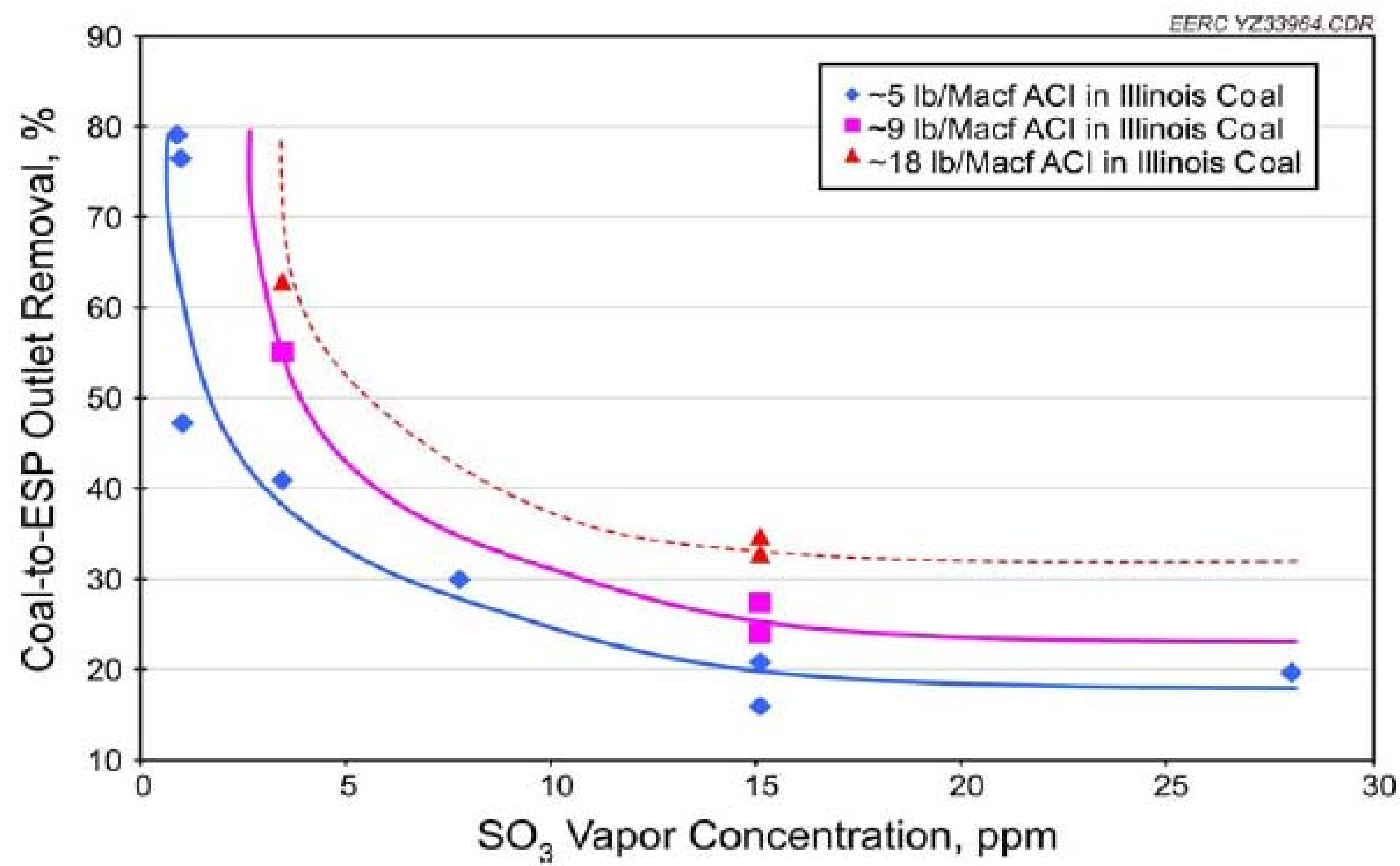


Mercury Control with Activated Carbon: Results from Plants with High SO_3

Paper #08-A-174-Mega-AWMA

Tom Campbell, Sharon Sjostrom, Martin Dillon, Paul Brignac
ADA Environmental Solutions
8100 SouthPark Way, Unit B
Littleton, CO 80120

Example Effect of SO_3 on ACI Capture



JV TASK 124 – UNDERSTANDING MULTI-INTERACTIONS OF SO_3, MERCURY, SELENIUM, AND ARSENIC IN ILLINOIS COAL FLUE GAS

Final Report

(for the period April 1, 2008, through March 31, 2009)

Prepared for:

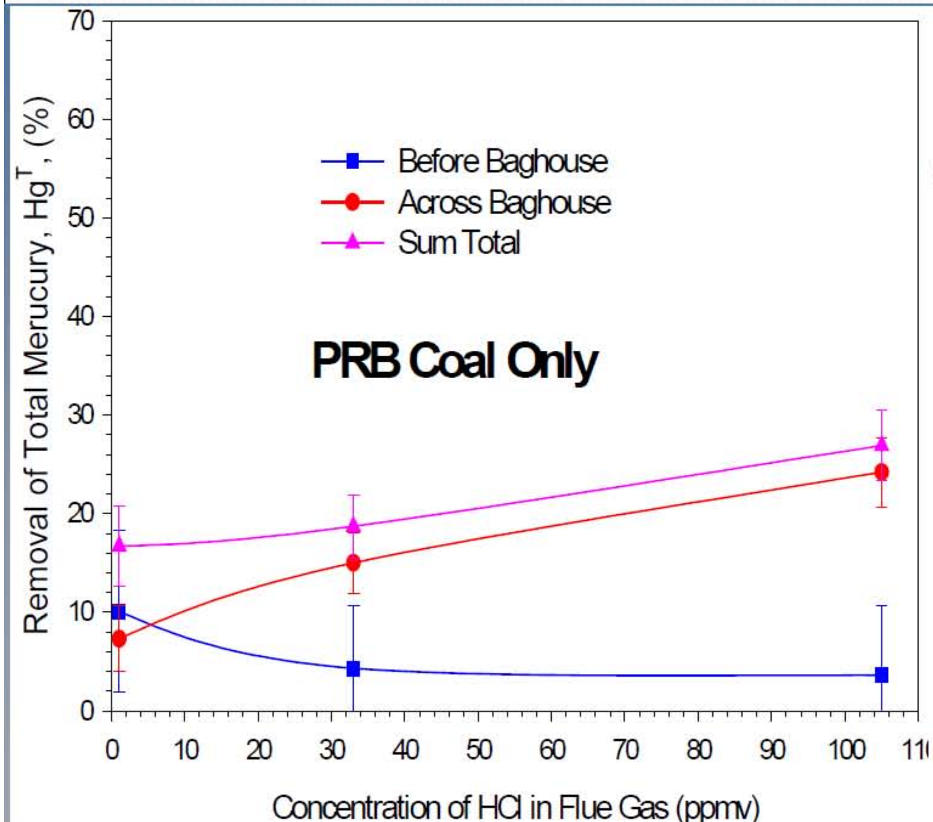
AAD Document Control

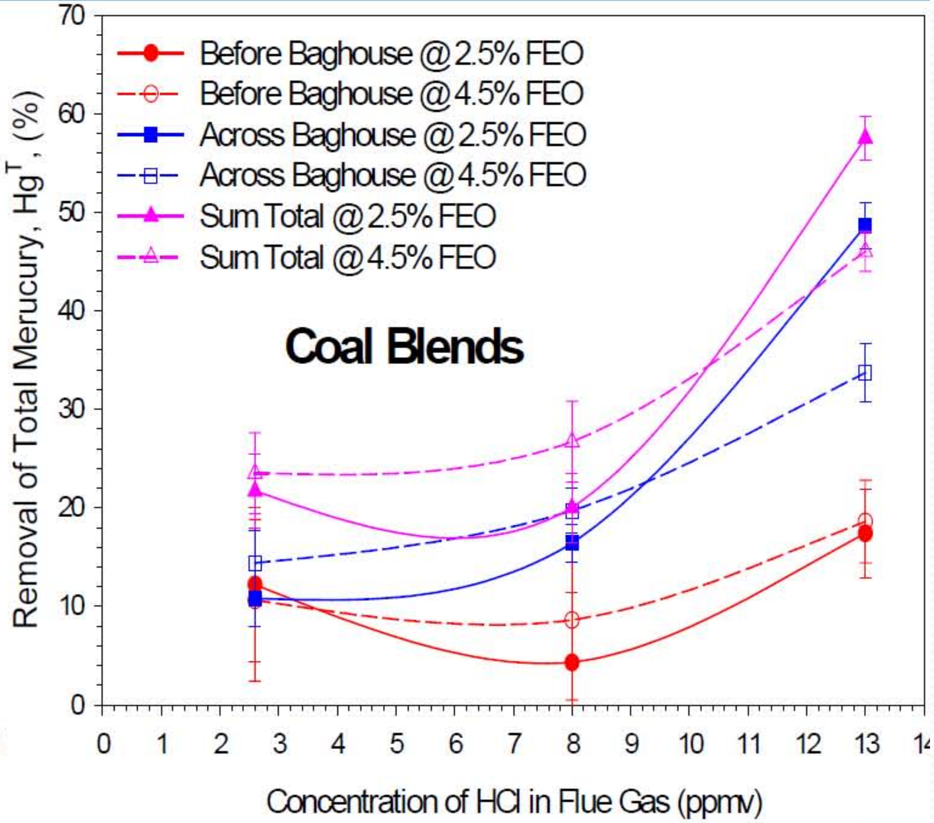
U.S. Department of Energy
National Energy Technology Laboratory
626 Cochrans Mill Road
PO Box 10940, MS 921-107
Pittsburgh, PA 15236-0940

Cooperative Agreement: DE-FC26-98FT40321
Project Manager: Jenny Tennant

Example Effect of HCl on Native Mercury Capture with UBC

Poor Removal Even with High Chlorine when UBC Low



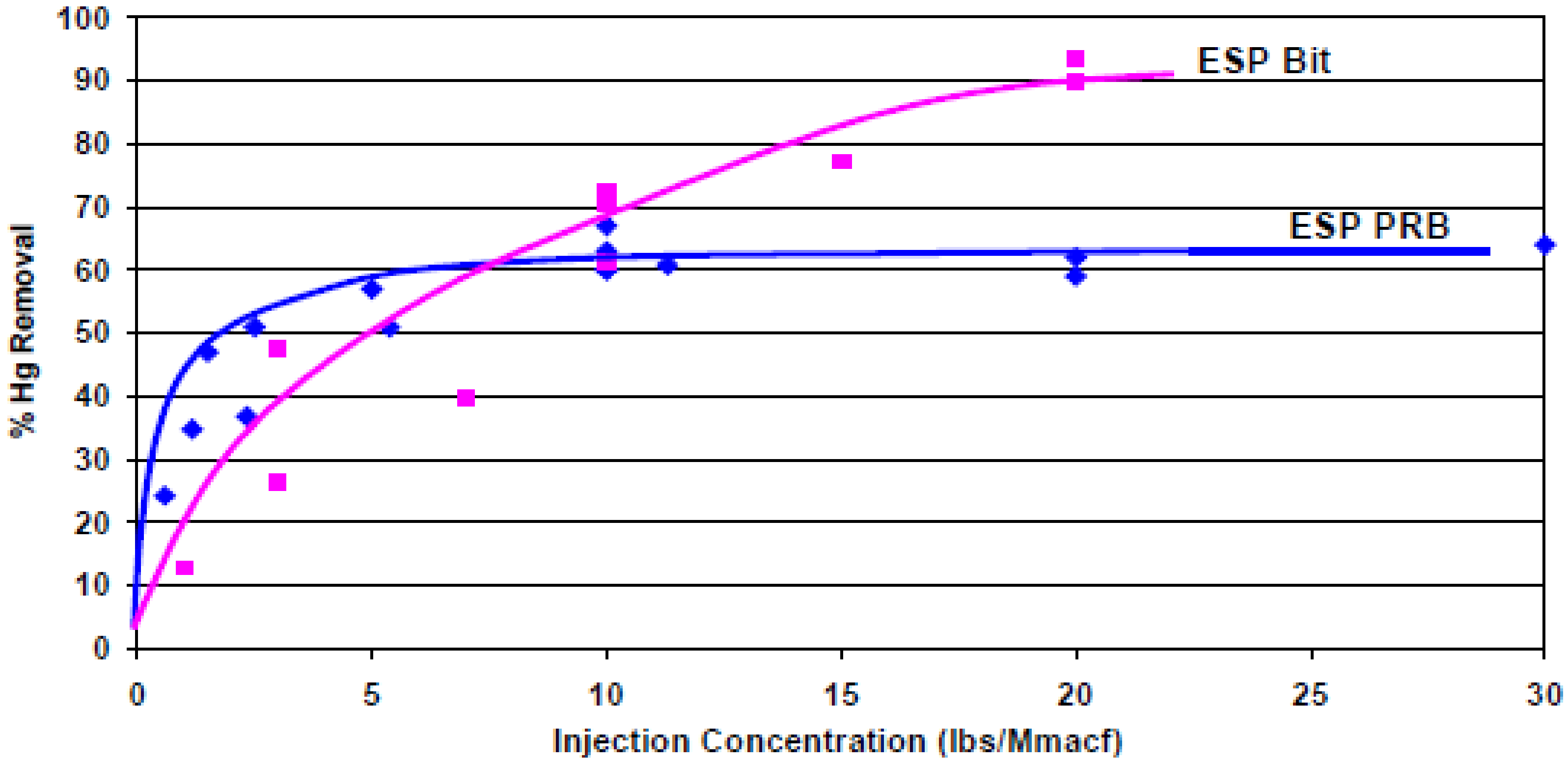


Southern Research Institute

Mercury Control with Calcium-Based Sorbents and Oxidizing Agents

Thomas K. Gale

Effect of Fuel Type on Activated Carbon Capture with ESP



Results of Activated Carbon Injection Upstream of Electrostatic Precipitators for Mercury Control

Paper No.

Travis Starns, Jean Bustard, Michael Durham Ph.D., Cam Martin, Richard Schlager, Sharon Sjostrom, Charles Lindsey, Brian Donnelly
ADA Environmental Solutions, LLC
8100 SouthPark Way, Suite B-2, Littleton, CO 80120
303-734-1727, 303-734-0330 (Fax)

Effect of Temperature on Activated Carbon Capture with ESP

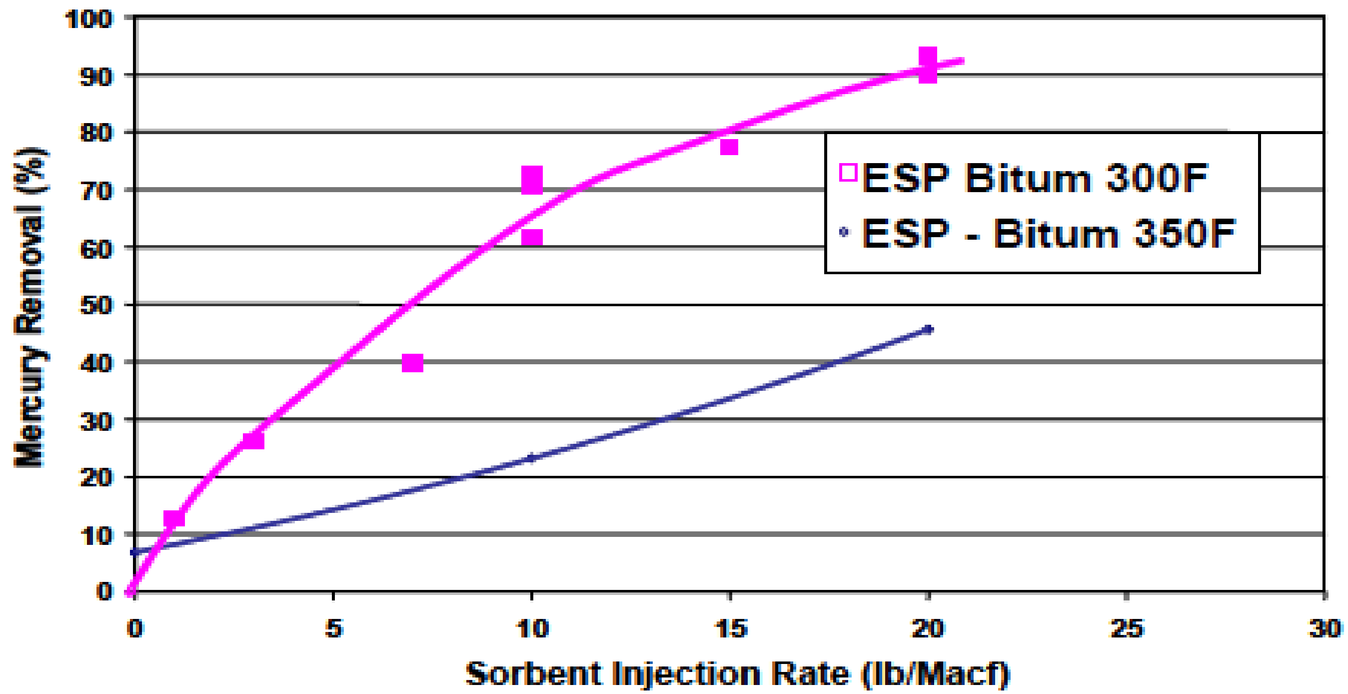
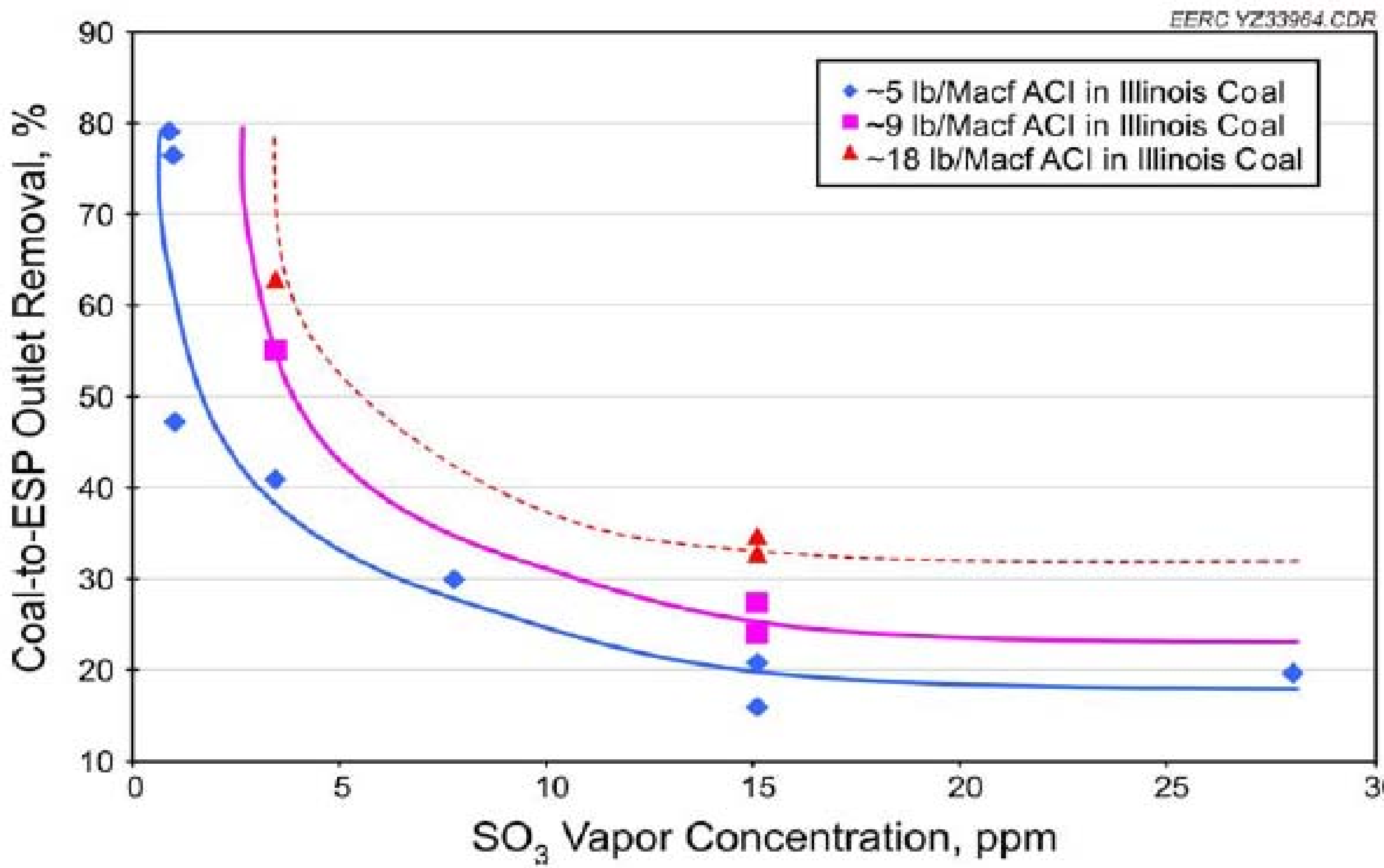


Figure 5. Temperature Impacts on the Performance of Activated Carbon on Gas Streams Containing Predominantly Oxidized Mercury

FULL-SCALE EVALUATION OF MERCURY CONTROL BY INJECTING ACTIVATED CARBON UPSTREAM OF ESPS

Michael Durham Ph.D., Jean Bustard, Travis Starns, Sharon Sjostrom, Charles Lindsey, Cam Martin, Richard Schlager
ADA-ES, Inc. 8100 SouthPark Way, Unit B, Littleton, CO 80120

Example Effect of SO_3 on ACI Capture



JV TASK 124 – UNDERSTANDING MULTI-INTERACTIONS OF SO_3, MERCURY, SELENIUM, AND ARSENIC IN ILLINOIS COAL FLUE GAS

Final Report

(for the period April 1, 2008, through March 31, 2009)

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AAD Document Control

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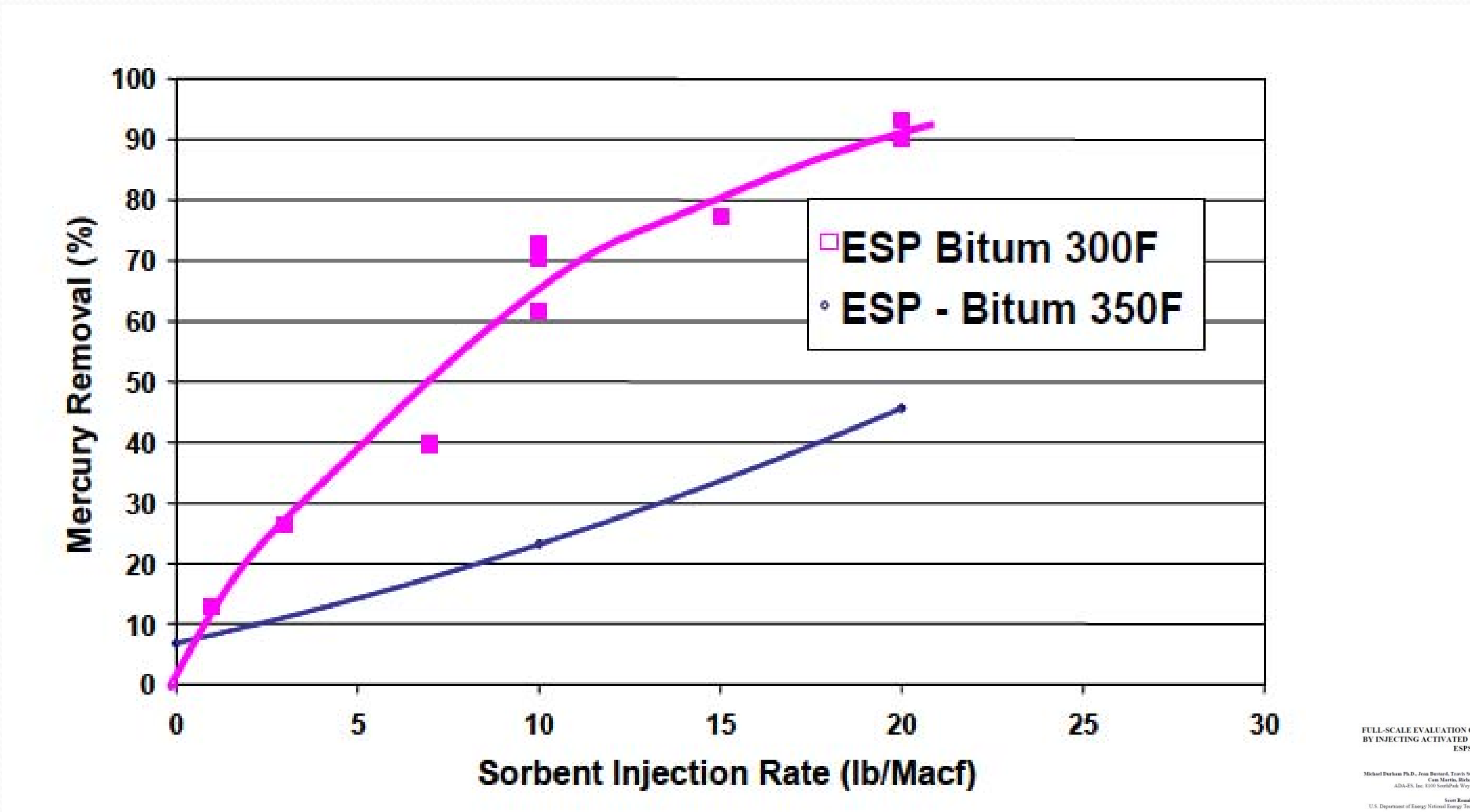
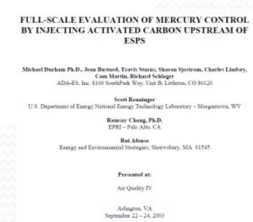
Project Manager: Jenny Tennant

Example Effect of Temperature on Sorbent Capture

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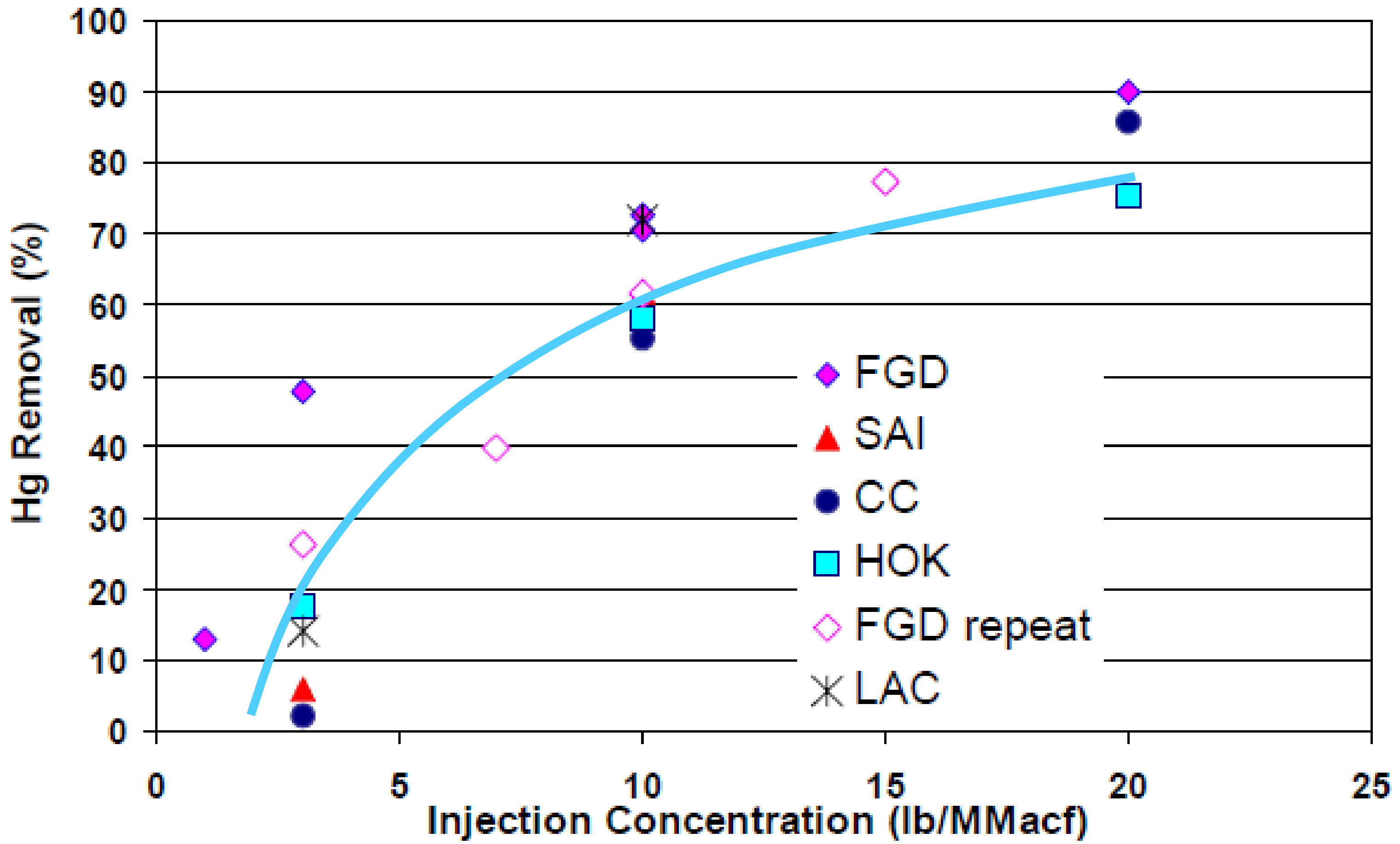
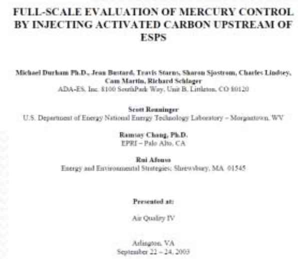
Example Effect of Sorbent Type and Injection Rate on Hg Capture Upstream of ESP





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CONCLUSIONS: CO-BENEFITS

- **Lot's of opportunities to improve current equipment to optimize mercury oxidation.**
- **Facilities firing high-halogen coals equipped with SCRs and wet scrubbers will be best suited to meet current regulations – optimization will still probably be necessary depending on fuel.**
- **Some facilities without wet scrubbers, but with good inherent mercury oxidation (including SCRs), may be able to meet regulations.**
- **Facilities firing low halogen fuels such as PRB and low-chlorine eastern bituminous coal will find it difficult to meet regulations with any configuration, even with optimization, unless some form of dedicated control is used (halogen injection, sorbent injection, etc.)**

CONCLUSIONS: DEDICATED CONTROLS

- Halogen addition very effective for improving mercury oxidation and capture, especially for halogen-depleted coals.
- Halogen injection may be needed even with sorbent injection to meet regulations, or at least to maximize efficiency and minimize sorbent costs.
- Lots of different options for sorbent injection location, design, particulate control device, sorbent design, etc. – no single solution.
- Sorbent injection has limitations and many of the optimization techniques used for co-benefit control will improve sorbent efficiency, and may in fact be required to meet regulations.