REINHOLD ENVIRONMENTAL Ltd.

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What's the Best Approach for Controlling Forced Oxidation Air Rates?

Presented at the Reinhold APC & Wastewater Roundtable, Charlotte NC

Gary Blythe, AECOM

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Why Control Forced Oxidation Air Rates?

- Historically not required on LSFO FGD systems
  - Large coal units typically base loaded
  - Higher than needed air rates at low load ensure low liquid-phase sulfite, high gypsum purity
  - Minor auxiliary power savings generally not important

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Why Control Forced Oxidation Air Rates (cont'd)?

– More drivers to control ox air rates today:
  - More coal units cycling and operating at low load
  - Under-deposit corrosion issues in alloy absorbers
  - Wet FGD used as a mercury control device
  - ELGs likely to require control of Hg, As, Se, NO_3^- in FGD wastewater discharges
    - o Concentrations of all of these species can be impacted by sulfite oxidation rate in FGD
  - Better net heat rate makes plant more competitive

– All of these drivers lead to a need to control ox air rates as sulfur capture rate varies

How to Best Control Forced Oxidation Air Rates?

1. No control; deal with the consequences
2. Control ox air rates based on slurry ORP
3. Use empirical, feed-forward control strategy
4. Measure liquid-phase sulfite concentrations, vary ox air rate to control to set point

Option 1. Don’t Turn Down Ox Air Rates at Low Load and/or Low Inlet SO_2

– Dissolved sulfite concentration below detection limits

– High ORP (>300 mV) at low load/inlet SO_2

– Hg in slurry transfers back to liquor phase, can re-emit or:
  - High PAC injection rates required upstream of FGD to control Hg in flue gas below MATS limit
  - High addition rates of re-emission additive to lower ORP, control re-emission

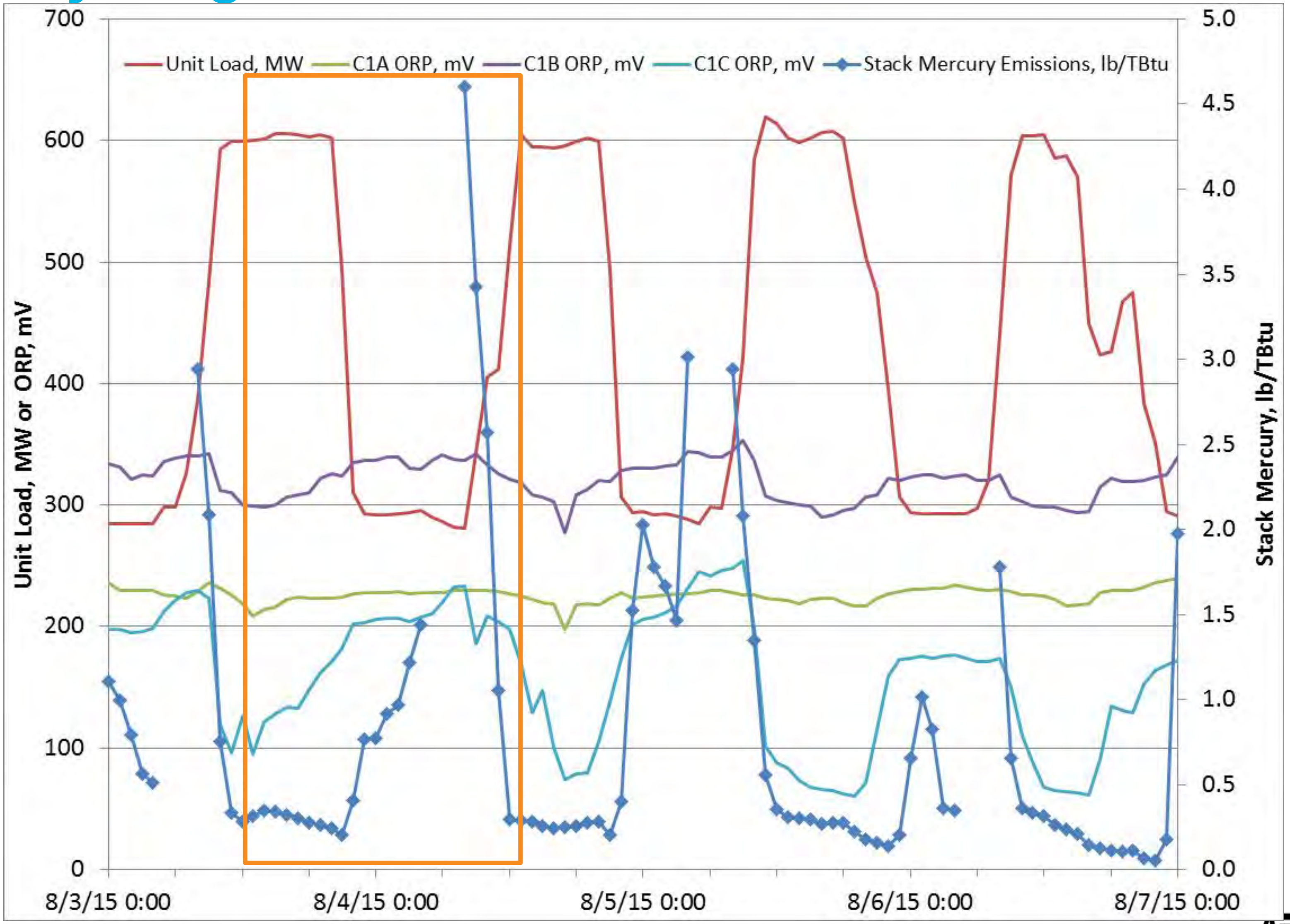
– Selenite in liquor oxidizes to selenate (w/o additive)

– Dissolved manganese oxidizes, precipitates on wetted surfaces; possible under-deposit corrosion (w/o additive)

Dealing with Over-oxidizing Conditions When Forced Ox Air Rates are too High

– Hg control:
  - Inject PAC upstream to control Hg below MATS limit at FGD inlet, and/or
  - Use re-emission additives to control sulfite oxidation rate/ORP, transfer Hg to FGD slurry solids
– Design wastewater treatment to handle high dissolved Hg, $SeO_4^{=}$, NO_3^-
– Apply measures to prevent under-deposit corrosion
  - Potential Adjustment Protection (PAP)
  - Wallpaper with higher alloy
  - Apply protective coatings
  - Use re-emission additive to control sulfite oxidation rate

Example Data for Forced Ox Air at Maximum Rate with Cycling Load



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Adjusting Forced Ox Air Rates to Respond to Unit Load, Inlet SO_2 Changes (Options 2-4)

– Turndown of air rates is limited on many FGD systems (a common issue)

– Range of turndown depends on blower/compressor type, ox air system design, type of air sparger in reaction tank

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Modifying Forced Ox Air Systems to Increase Turndown

– Replace manual valves with remotely operated valves
– Modify piping so one blower can supply air to two FGD systems
– Possibly use VFD on blower motor
– Add or increase size of blow-off valves/silencers
– Take some fixed-sparger headers out of service

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Option 2. Adjust Forced Ox Air Rates to Control ORP

- Automating control may be covered by MHI patent
- Manual adjustment approach requires considerable operator attention
  - Operators unsure how big an adjustment to make on air rates
  - Air flow rate instruments often inaccurate or inoperable, makes it difficult for operators to gauge “where they are”
- How reliable is ORP measurement?
  - Probes require as much diligence to maintain as pH
  - ORP measurements impacted by other redox reactions in wet FGD slurry

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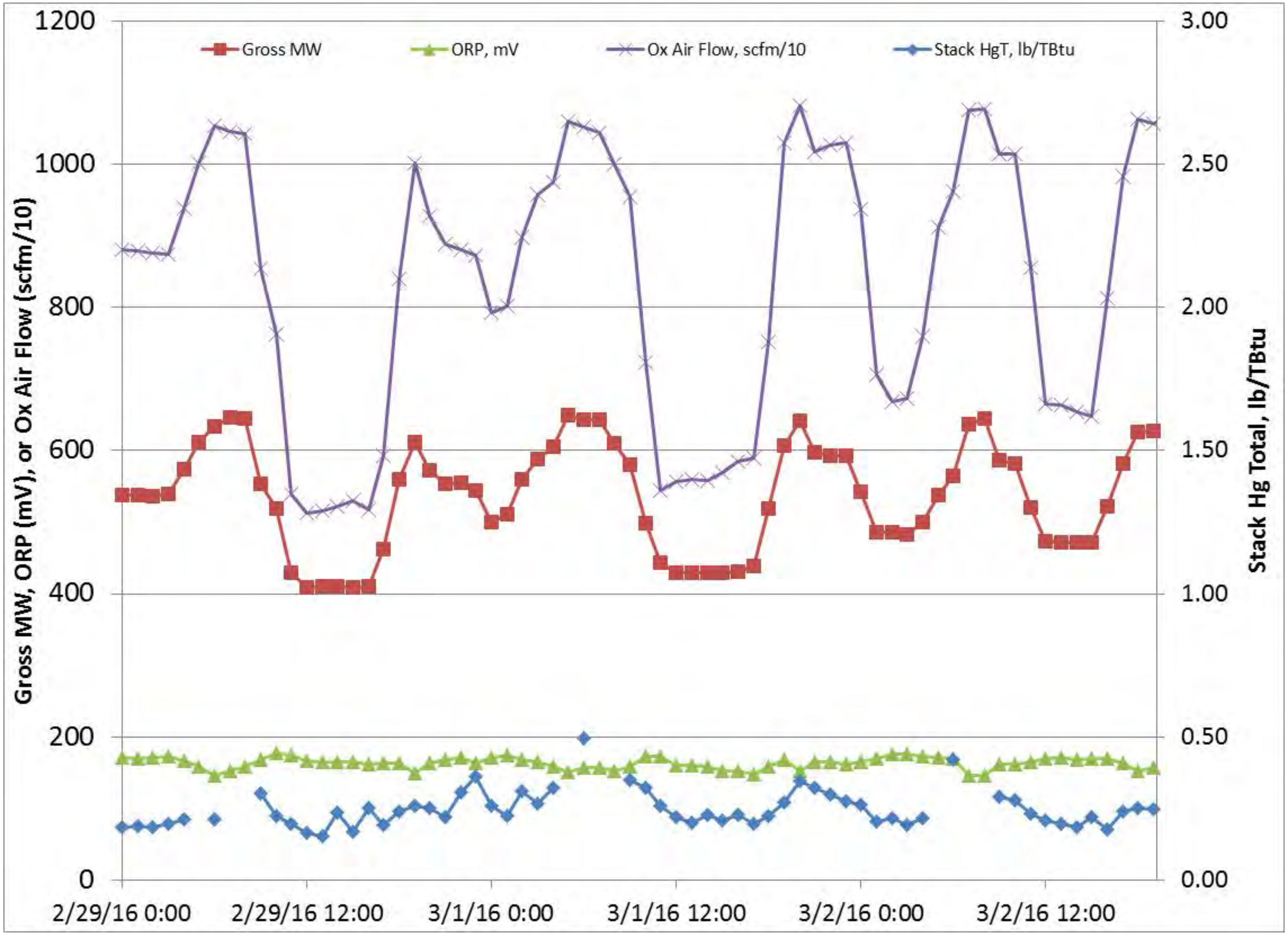
Option 3. Empirical Correlation to Control Forced Ox Air Rate

– Automate forced ox air rates to adjust for unit load, FGD inlet SO_2 concentration

– Empirical control algorithm programmed into DCS
  - Upgraded air flow instrumentation may be needed
  - Works best with a reliable inlet SO_2 monitor
  - Need to account for higher O_2 in flue gas at low load & for number of recycle pumps running

– No slurry probes or monitors needed, but:
  - Fine tuning may be needed to control sulfite oxidation rates over full range of unit load, coal S
  - Provide operator over-ride capability

Example Data with Feed Forward Forced Ox Air Control



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Option 4. Use Sulfite Monitor for Feedback Control of Forced Ox Air Rate

– Proprietary instrument developed by Alstom AQCS Service Solutions (now part of GE)
  - Continuous dissolved sulfite concentration measurement in a flowing, ambient pressure slipstream
  - Voltammetry method
  - Calibrated by comparing output to manual measurements

– Patented approach to use analyzer output as a set point for controlling ox air flow rate

– Requires analyzer on each absorber reaction tank

GE Commercial Sulfite Analyzer

– Designed to operate in slurry service
  - “Wiper” rotates to keep probe tip clean
  - Weekly cleanup with soft brush to avoid solids buildup

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Results for Sulfite Control of Forced Oxidation Air Rates

- Test conducted on 1 of 3 absorber modules on a 1300-MW unit firing medium-sulfur bituminous coal
  - Co-funded by utility and EPRI, in-kind support from GE
  - Spray towers with fixed sparger grids in reaction tanks
  - Tests conducted at ≥60% load to avoid minimum air flow limits imposed by fixed sparger design
- Note that results similar to what follows could be achieved with Options 2 or 3 if adequate control of sulfite oxidation rate is achieved

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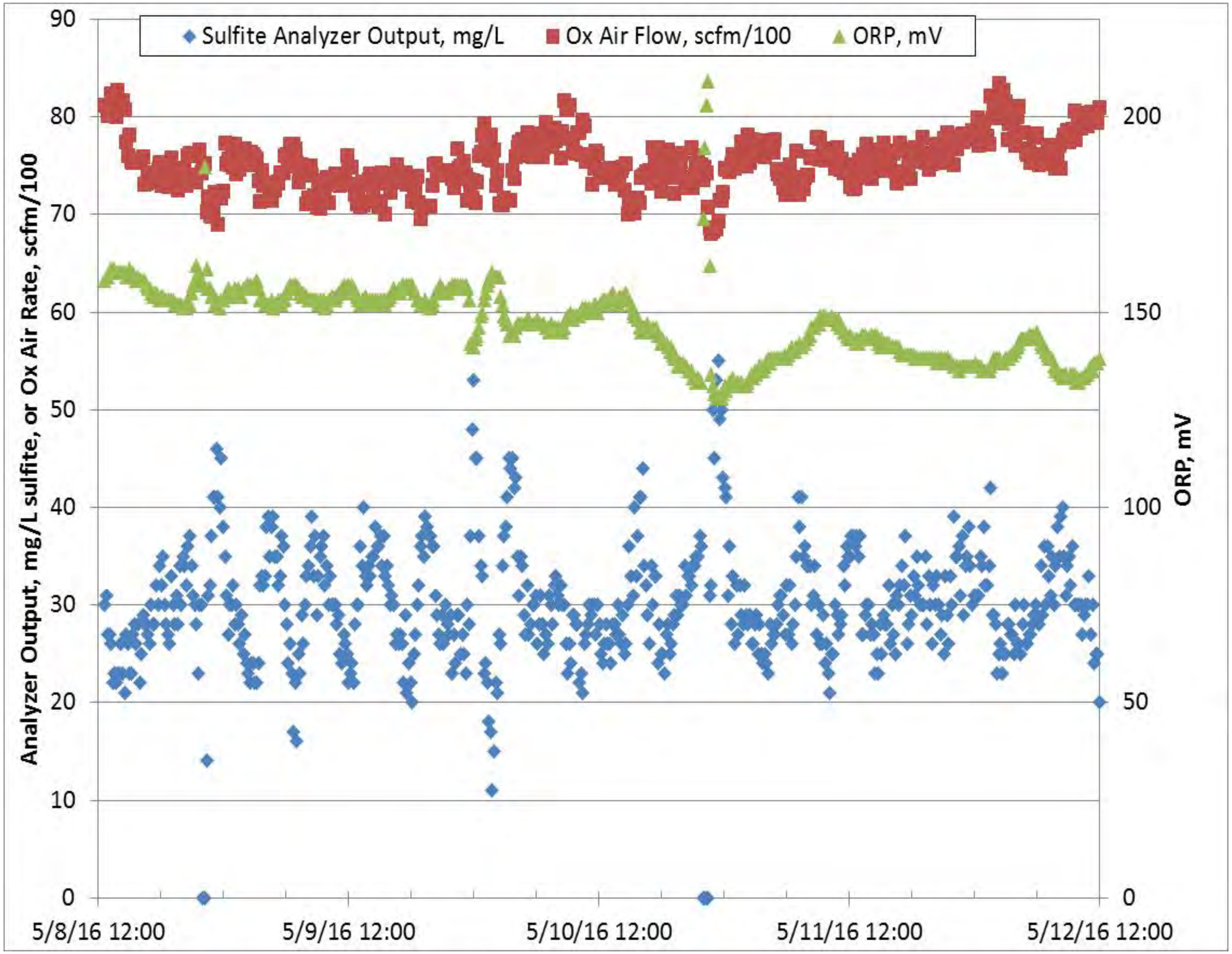
Analyzer Output, Ox Air Rate, and ORP during Sulfite Control Operation



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Analyzer Output versus Lab Measurements during Sulfite Control Operation

Date	$SO_3^=$ by IC, mg/L	$SO_3^=$ by Analyzer, mg/L	Relative % Difference
10/19/15	<1.1	Not in service	-
10/20/15	<1.1		-
5/11/16	20	27	30
5/11/16	21	29	32
5/11/16	20	33	49
5/12/16	25	35	33
6/15/16	81	79	3
6/15/16	73	79	6
6/15/16	74	78	5
2/16/17	22	24	8
2/16/17	24	23	6
2/16/17	27	27	4

All sulfite values by analyzer reflect calibration from 10/21/15

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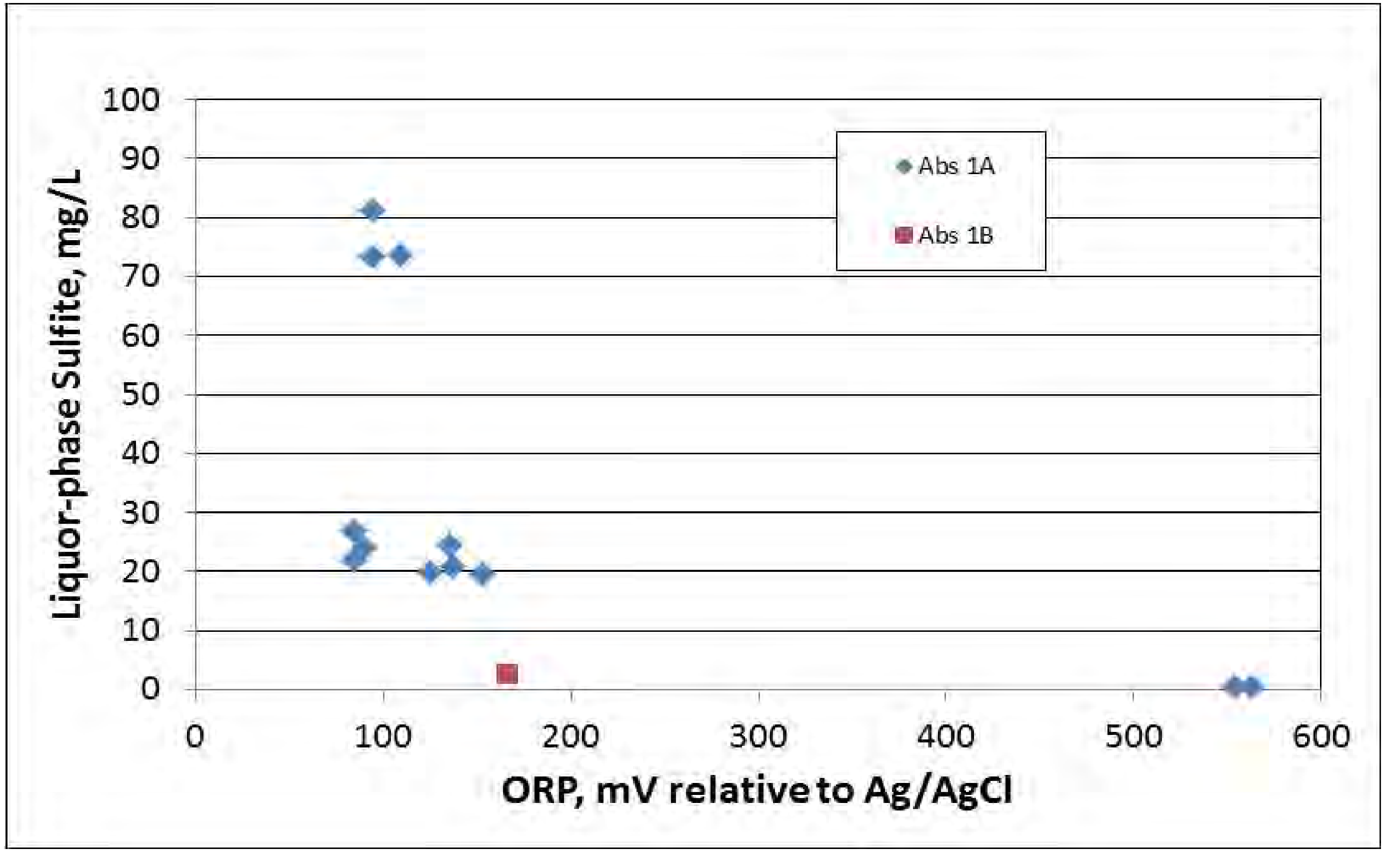
Lab Result for Liquor-phase Sulfite vs. ORP by Hand-held Instrument



Note wide range of ORP values at 20-30 mg/L sulfite

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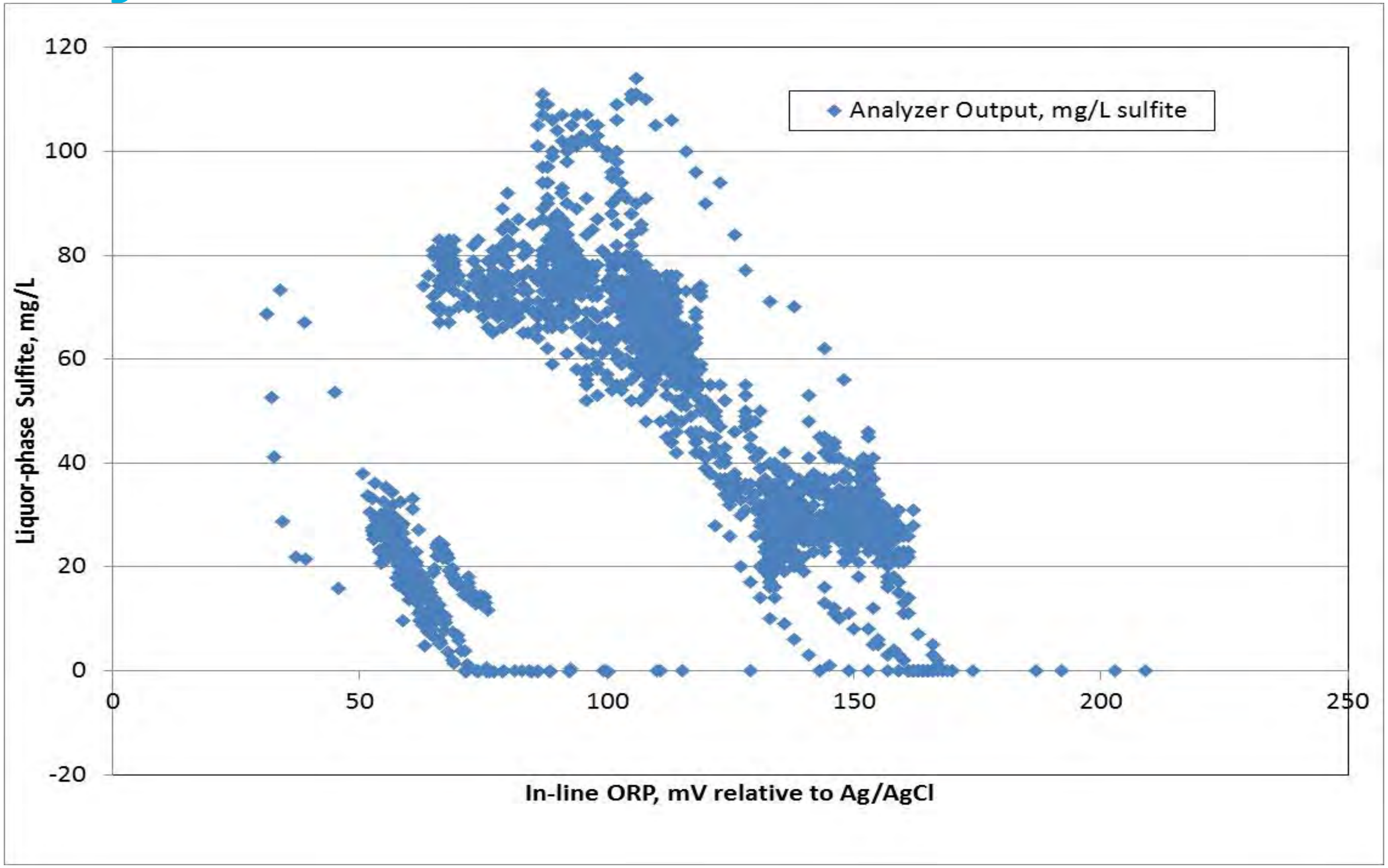
Analyzer Result for Liquor-phase Sulfite vs. ORP by In-line Measurement



Controlling ORP at 150 mV would result in over oxidizing at some times

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Absorber Hg Control Results

Test Condition	Inlet Hg Oxidation, %	Hg Removal across FGD	Hg Re-emission across FGD, % of inlet Hg2+	Outlet Hg, lb/TBtu
Baseline, no sulfite control	98	60	38	1.0
Sulfite Control, 20-30 mg/L	97	98	0	0.2
	99	99	0	0.1
Sulfite Control, 70-80 mg/L	95	96	0	0.1

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Test Absorber Average Hg Phase Partitioning Results

Condition	ORP, mV	Dissolved Hg, ng/L	Hg in slurry solids, µg/g	% of total Hg in slurry liquor	% of total Hg in slurry solids
Baseline, no sulfite control	560	75,000	0.17	70	30
Sulfite control, 20-30 mg/L	140	90	0.55	0.09	99.91
	90	50	0.55	0.05	99.95
Sulfite control, 70-80 mg/L	100	160	0.58	0.15	99.85
No sulfite control*, Nalco 8034+	170	20	0.55	0.02	99.98

*Sister absorber using Nalco 8034+ re-emission control additive

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Test Absorber Average Se Phase Partitioning Results

Condition	ORP, mV	Dissolved Se, µg/L	Se in slurry solids, µg/g	% of total Se in slurry liquor	% of total Se in slurry solids
Baseline, no sulfite control	560	610	1.6**	67	33
Sulfite control, 20-30 mg/L	140	290	3.4**	29	71
	90	140	2.3	25	75
Sulfite control, 70-80 mg/L	100	340	2.8**	39	61
No sulfite control*, Nalco 8034+	170	150	2.7	24	76

*Sister absorber using Nalco 8034+ re-emission control additive
**Result is above MDL but below reporting limit, estimated result

Test Absorber Average Se Speciation Results

Condition	ORP, mV	Dissolved Se, µg/L	% Selenite	% Selenate	% Other Selenium Species
Baseline, no sulfite control	-	-	-	~99*	-
Sulfite control, 20-30 mg/L	90	140	93	6	1
Sulfite control, 70-80 mg/L	100	340	97	3	<1
No sulfite control,** Nalco 8034+	170	150	53	47	1

*Previous data from the same FGD system at baseline operation

** Sister absorber using Nalco 8034+ re-emission control additive

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Test Absorber Average Total Nitrate/Nitrite Results

Condition	ORP, mV	Total NO_3^-/NO_2^-, mg/L	Apparent S/N species, mg/L as $SO_4^=$
Baseline, no sulfite control	560	16	80
Sulfite control, 20-30 mg/L	140	5	620
	90	5	NA
Sulfite control, 70-80 mg/L	100	2	260
No sulfite control*, Nalco 8034+	170	8	NA

Nitrate concentrations may be lowered by conversion to sulfur-nitrogen species

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Test Absorber Average Mn Phase Partitioning Results

Condition	ORP, mV	Dissolved Mn, µg/L	Mn in slurry solids, µg/g	% of total Mn in slurry liquor	% of total Mn in slurry solids
Baseline, no sulfite control	560	50	22	1	99
Sulfite control, 20-30 mg/L	140	3800	3.5	86	14
	90	5600	4.1	88	12
Sulfite control, 70-80 mg/L	100	3700	4.7	81	19
No sulfite control*, Nalco 8034+	170	5000	7.1	79	21

*Sister absorber using Nalco 8034+ re-emission control additive

Mn becomes insoluble at highly oxidizing conditions; can scale on alloys of construction, exacerbate under-deposit corrosion

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Potential Power Savings (estimates for controlling sulfite on all absorbers at host unit)

Parameter	50% to 100% Load, Full Ox Air Flow	100% Load, Sulfite Control	50% Load, Sulfite Control
Air to 3 Absorbers, SCFM	30,775	21,525	15,375
No. of Operating Air Blowers	2	2	1
Total Blower Power, kW	1910	1492	955
Power Savings, kW	-	**418**	**955**

Summary

- Many benefits from controlling forced ox air flow to avoid over-oxidizing conditions
  - Improved Hg capture, less need for PAC injection or re-emission additives
  - Lower concentrations of ELG constituents in wastewater
  - Less tendency for under-deposit corrosion of alloys of construction
  - Less power consumption by forced ox blowers, depending on blower type and system configuration

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Summary (continued)

- Three options discussed for controlling ox air rates:
  - **ORP control**: can be imprecise, other redox reactions impact probe readings, possible patent issues
  - **Feed forward algorithms**: empirical, may have to be tuned as process changes occur
  - **In-line sulfite analyzer control of air rate**: direct control of sulfite oxidation rate; down side is cost of analyzer, particularly for multi-module systems
- Any control option may require modifications to ox air system to improve turndown

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Questions or Comments?

Gary Blythe

(512) 419-5321

Gary.Blythe@AECOM.com

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