

# **REINHOLD ENVIRONMENTAL Ltd.**



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FirstEnergy, Southern Company & TVA

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## *The “Little Precipitator” that Could*

*by John A. Knapik, B&W ESP Applications Engineer  
and Doug Hartman, FirstEnergy Manager of  
Environmental Field Operations*

# Overview

- John Knapik will handle the first part of the presentation, and then the formidable Doug Hartman, will rap things up
- The presentation utilizes the review of an actual precipitator to demonstrate whether it will be Mercury and Air Toxics Standard (MATS) compliant for particulate matter, PM (< 0.030#/MMBtu).
- The analysis will show that “size alone”, does not determine the ability of an ESP to collect dust.
- Doug will end with an evaluation of his *Little ESP that Could*
- The units discussed by each author are not the same unit



# *Gathering Data*

- First step in a MATS compliance evaluation is to gather as much pertinent data as possible.
- Drawings of the ESP and ductwork
- At least 2, and preferably 3, of the last PM tests
- Size and description of the existing ESP design, sorbent systems, T-R sets, AVC & rapper controls
- 1 or 2 of the most recent inspection reports
- Any previous flow modeling
- Fuel and ash analysis
- Anticipated PAC and DSI injection materials and rates for either MATS and/or Cross State Air Pollution Rule (CSAPR) compliance
- Minimum 1 month of plant historical data on boiler load vs. opacity
- Electrical readings for the ESP at full load, and at the time of the PM testing

*A lot of things to consider in an ESP Review. We use the Scorecard Method which helps in easily grasping the situation*

		Client:	YOUR STATION		
		Location:	ANYWHERE USA		
		Application:	Cold-side ESP		
			7/6/2011		
		Item	Units	Unit #2	Recomnd'd
1	Operating & Performance Data	Gas Volume	acfm	800,000	
2		Gas Velocity	ft/sec	4.34	< 4.0
3		Gas Temperature	°C		
4			°F	369	
5		Inlet Dust Loading	gr/dscf		
6		Treatment Time	sec	6.3	> 11
7		Aspect Ratio	ft/ft	1.03	> 1.2
8		Specific Collecting Area (SCA) <sub>10</sub>	ft <sup>2</sup> /kacfm	n/a	
9		Specific Collecting Area (SCA) <sub>9</sub>	ft <sup>2</sup> /kacfm	369	> 380
10	Precipitator Arrangement	Preceding Dust Collectors - Type		NONE	
11		No. & Arrangement	No.	N/A	
12		No. of Precipitators (ESP)	No.	1	
13		No. of Chambers/ESP	No.	3	
14		No. Electrical Fields/ESP	No.	4	4 or greater
15		No. Electrical Cells/Transformer	No.	1	
16		No. Gas Passages/Chamber	No.	39	
17		Width of Gas Passage	Inches	9	
18	Collecting System	Nom. Width	feet	9	
19		Nom. Height	feet	35	
20		Treatment Length	feet	36	
21		Collecting Area/Transformer, Field 1	ft <sup>2</sup>	24,570	< 18,000
21		Field 2-4	ft <sup>2</sup>	24,570	< 18,000
22		Collecting Area/ESP	ft <sup>2</sup>	294,640	
23	High Voltage System	HV Electrode Type		Wght'd Wire	Rigid Elec.
24		HV Electrode Type & Thickness	Inch	0.109" dia.	
25		No. Support Insulators/ Frame	No.	2	
26		HV Frame Total/Field	No.	1	
27	Transformer-Rectifiers	No. Total/ESP	No.	12	
28		No. Total/Field	No.	3	
29		Rating Field 1-2	KV/mA	45/1200	50KV
30		Rating Field 3-4	KV/mA	45/1500	50KV
31		Current Density (microAmps/ft <sup>2</sup> )			
32		Field 1-2	as noted	48.8	25 - 50
33	Field 3-4	as noted	61.0	40 - 70	
34		Type of Power Supply		T/R	
35	Rapping System	Type Collecting System Rapper		AVC SPCLST	
36		No. of Plate Rappers/Box	No.	168	
37		Collecting Area / Rapper	ft <sup>2</sup>	1755	< 1500
38		Type HV System Rapper		NEUNDORFER	
39		No. of HV Rappers/HV Frame	No.	5!	
40		Linear Ft./HV Rapper	Fl.	3276	< 4000
41		Type Distribution Plate Rapper		NEUNDORFER	
42		No. of Dist. Plate Rapper/Ch.	No.	6	

## *Most Important Factors Affecting ESP Performance*

1. Ash Resistivity
2. Inlet Particle Size Distribution and Concentration
3. Electrical Energization
4. Specific Collecting Area (SCA)
5. Dust Loss Factors

## *The Little Precipitator that Could (LPTC), Boiler Data*

- A B&W cyclone furnace with seven cyclones
- The unit is rated at 330 MW(gross) and typically runs at full load of 300MW with peaks to 315MW
- The furnace is pressurized and the ESP is under positive pressure
- An over fired air and an SNCR system were added for Nox control
- CaBr<sub>2</sub> is added to the coal for mercury control
- The air preheater is a two pass tubular design preceding the ESP (cold-side ESP)



## *Cyclone Boiler Impact on ESP Performance*

- The B&W cyclone furnace was developed in the 1940s to burn coal grades that are not well suited for pulverized coal (PC) combustion. The ash from these coals has a low melting (fusion) temperature and would enter the superheaters of PC units in a molten state, creating severe slagging
- A cyclone boiler yields a much finer particle size distribution (PSD) than a PC boiler
- Finer dust is more difficult to collect and requires either a larger sized (SCA) ESP or higher power input or both.
- The cyclone produces more slag and less flyash (30 to 40% vs 80% for a PC boiler). However the lower inlet loading doesn't overcome the negative effects of the finer particle size.
- The pressurized furnace and tubular air heater mean a minimum of air inleakage throughout the system, including the ESP. This is a plus.



## Typical PSD at ESP Inlet (3.2 vs. 12)

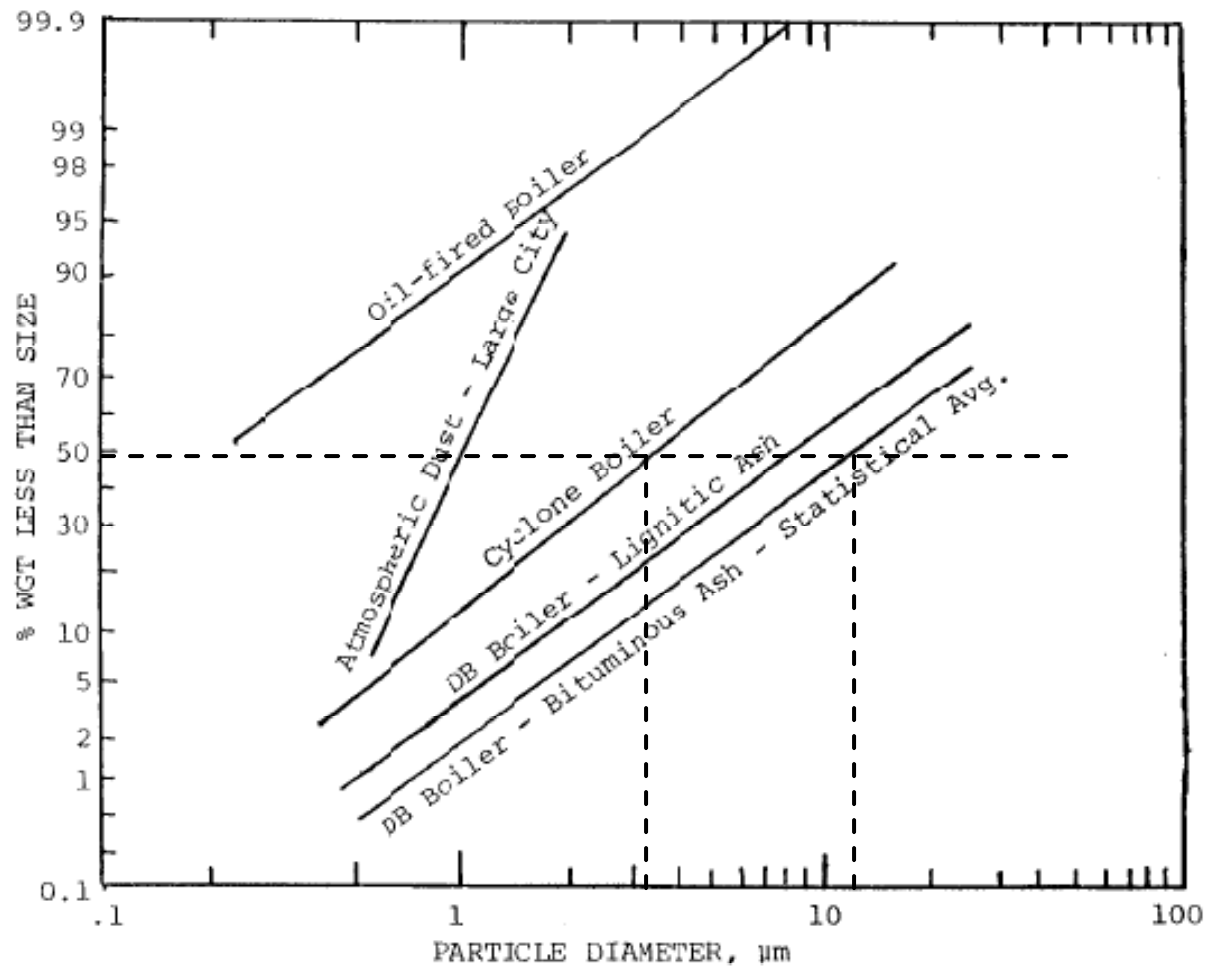


Figure 6. Typical Fly Ash Particle Size Distributions ESP Inlet

## The LPTC, Typical Boiler Data

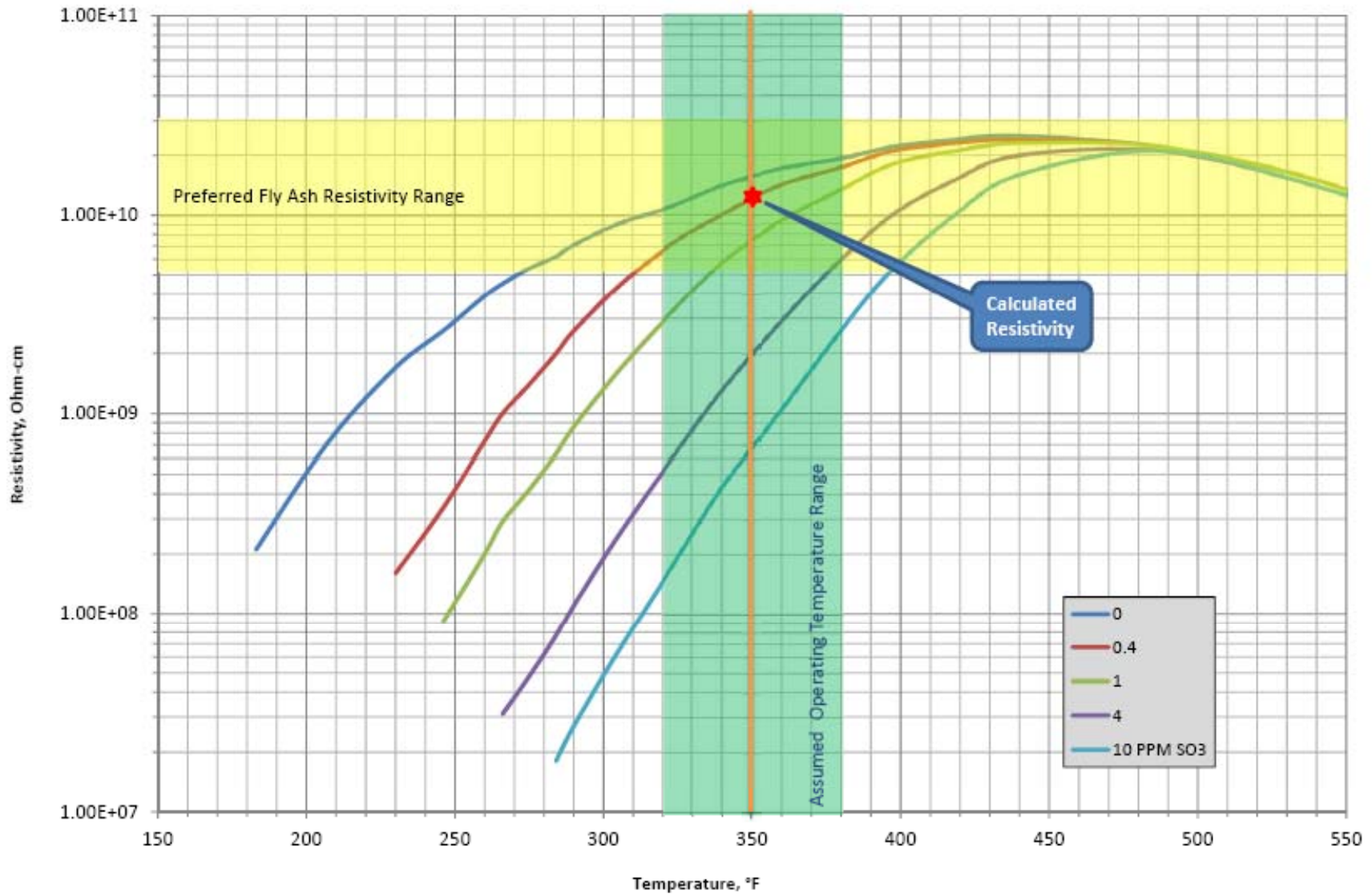
<b>Table A: Unit Operating Conditions</b>	<b>Units</b>	<b>LPTC</b>	<b>Score</b>
<b>Actual Conditions @ Full Load</b>		<b>B&amp;WCyclone</b>	
<b>Gross MW</b>	<b>MW</b>	<b>313</b>	
<b>"A" Air Heater Gas Out Temp'r'tre</b>	<b>°F</b>	<b>315</b>	<b>&lt; 310</b>
<b>"B" Air Heater Gas Out Temp'r'tre</b>	<b>°F</b>	<b>NA</b>	<b>&lt; 310</b>
<b>Total Combustion Air</b>	<b>Klb/hr</b>	<b>3256</b>	
<b>Coal Feed Rate</b>	<b>Klb/hr</b>	<b>339</b>	
<b>Steam Flow or Feedwater Flow</b>	<b>Klb/hr</b>	<b>1999</b>	
<b>Boiler Exit O<sub>2</sub> &amp; CO</b>	<b>%/PPM</b>	<b>1.9/52</b>	
<b>Typical Opacity at Full Load</b>	<b>%</b>	<b>14</b>	<b>&lt; 9</b>
<b>SO<sub>3</sub> Injection Rate</b>	<b>PPM</b>	<b>24</b>	
<b>Any Other Sorbents (ACI,Trona,Lime)</b>		<b>No Current</b>	
<b>NOX Control (OFA, Lo Nox Brnr, SCR)</b>	<b>List</b>	<b>OFA, SNCR</b>	
<b>Type of Air PreHeater</b>	<b>Type</b>	<b>Tubular</b>	

## The LPTC, PRB Fuels Data

<u>Table B: Fuel Characteristics</u>	Units	LPTC	Score
<b>Range of Typical Values as Received</b>		<b>Antelope+Black Thunder</b>	
<b>Average Sulfur Content</b>	%	<b>0.28</b>	
<b>Average Ash Content</b>	%	<b>5.38</b>	
<b>Average Moisture Content</b>	%	<b>27</b>	
<b>Average BTU per Lb.</b>	BTU/#	<b>8797</b>	
<b>Average Ash Sodium Oxide</b>	%	<b>1.49</b>	

- The resistivity of the flyash will be determined by the sulfur content in the coal and the sodium content in the ash
- The sulfur content is very low (detrimental).
- The sodium content is reasonable, but must be viewed in conjunction with the % weight in the ash of CaO, MgO, SiO<sub>2</sub>, and Al<sub>2</sub>O<sub>3</sub> (increase resistivity).
- The Black Thunder coal (the worst actor) has a resistivity of  $4 \times 10^{11}$  ohm-cm at ESP operating temperature.
- The SO<sub>3</sub> injection rate of 24ppm seems high, but could be required to overcome the higher concentrations of free lime (CaO) in the ash

## Computer Modeling of Ash Resistivity for Fuels Burned



## *ESP emissions impact from high resistivity: sodium changes in coal ash*

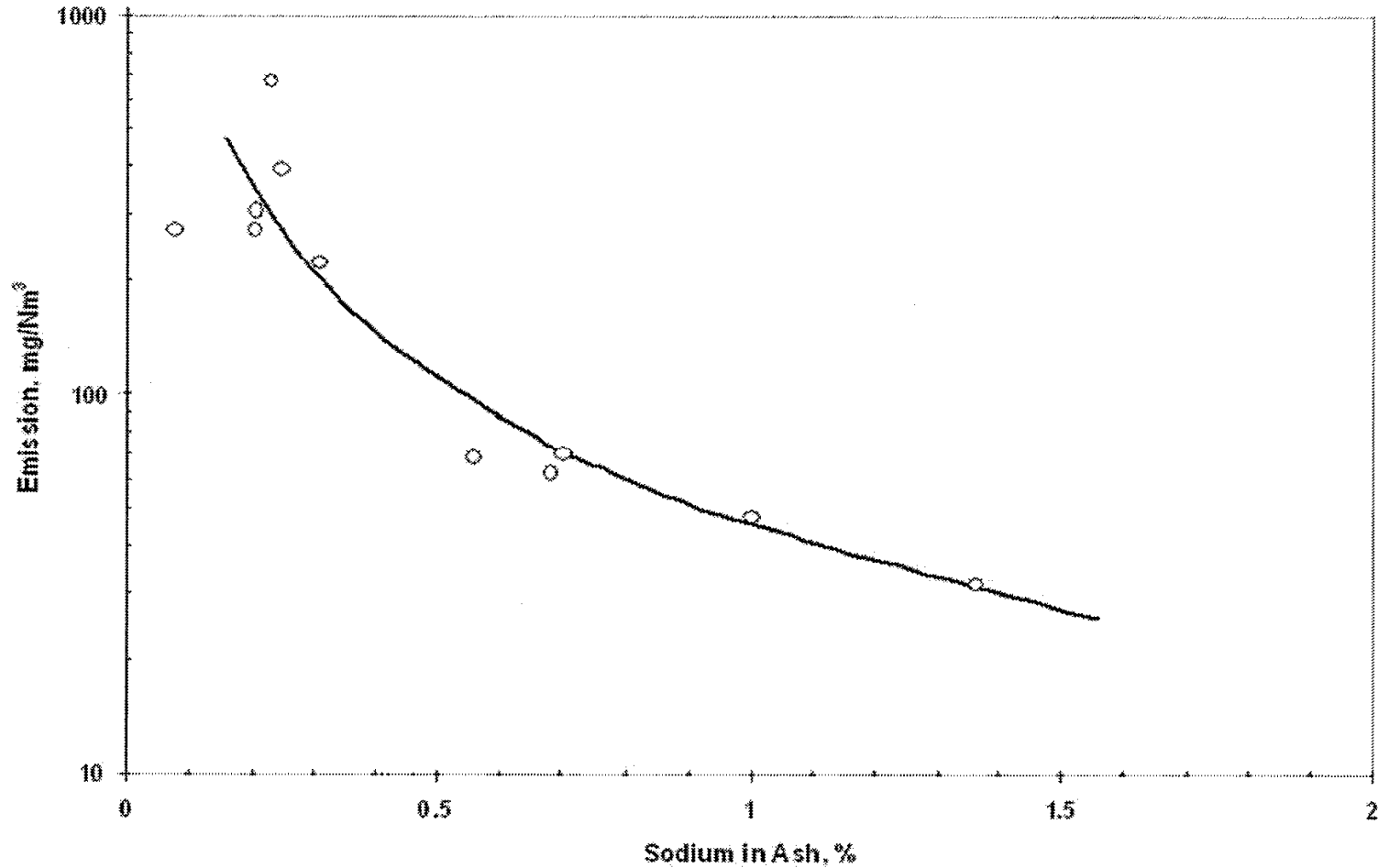
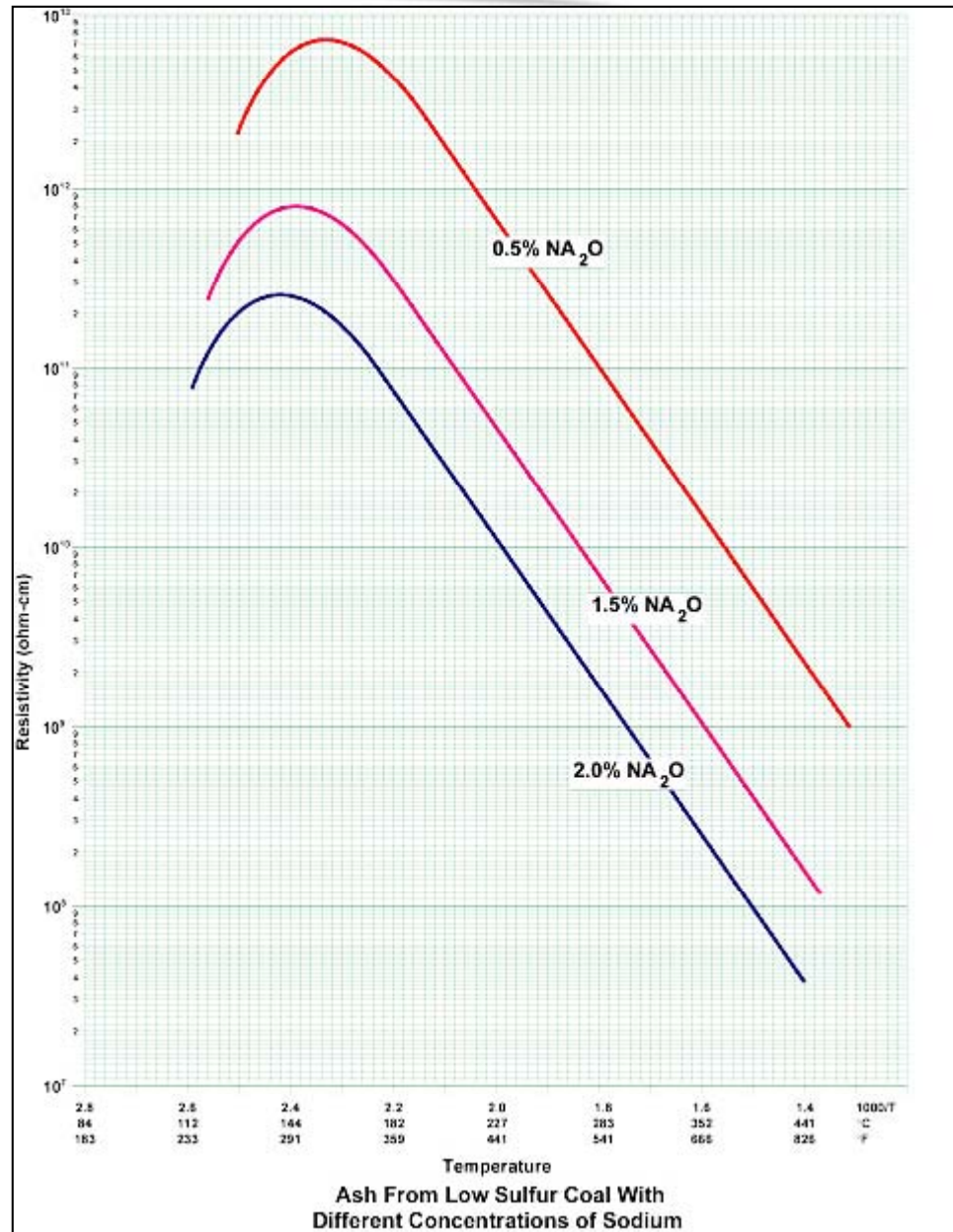


Figure 6-5. The effect of sodium oxide in the ash on an ESP's efficiency.

# Ash from Low Sulfur Coal with Different Concentrations of Sodium

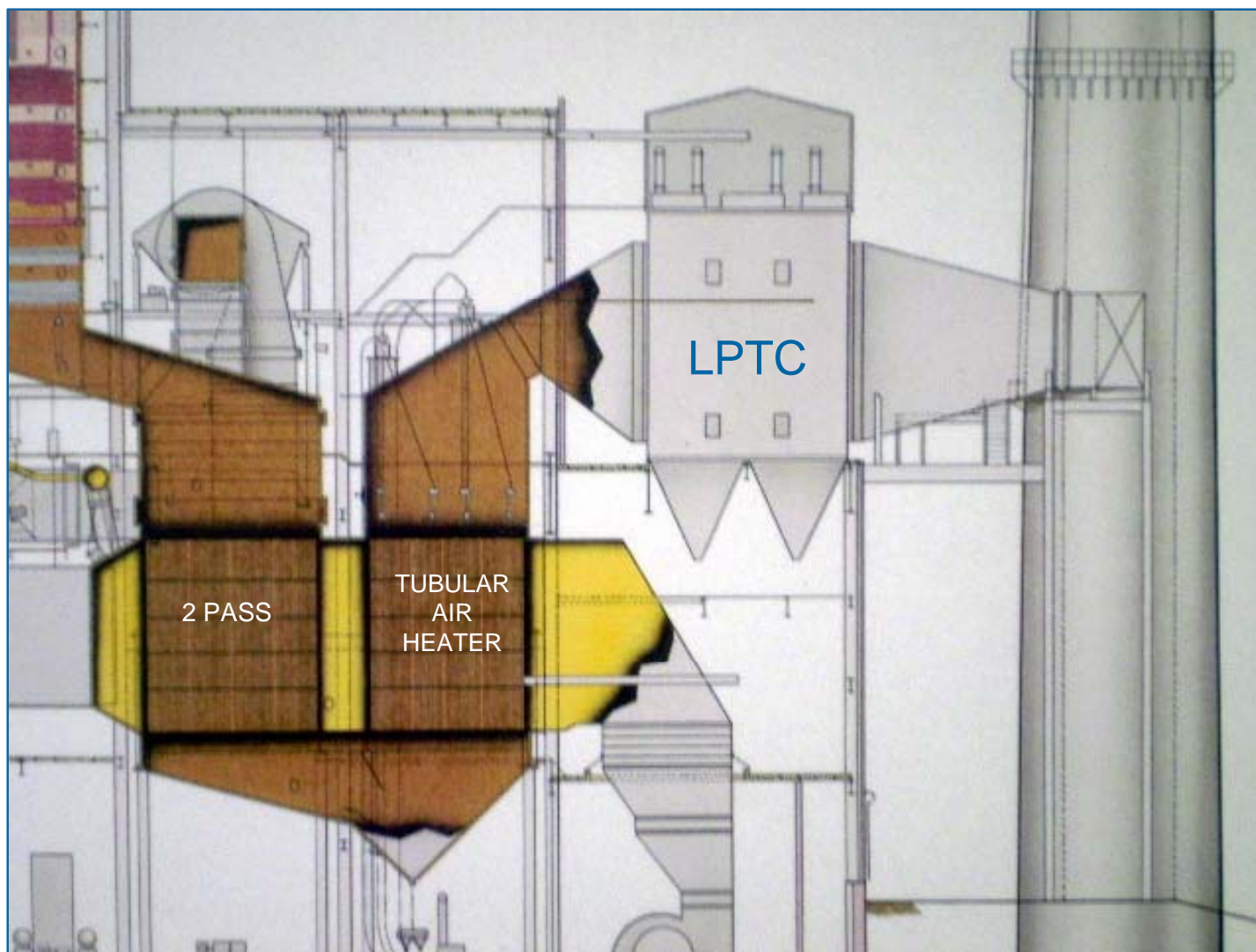


## *The LPTC ESP Data*

- A 1970's vintage weighted-wire Buell "B" ESP, originally designed to collect flyash from a high sulfur coal.
- It has 3 chambers, with each chamber being 40 gas passages wide at 9" spacing.
- There are 2 mechanical fields (9' x 30') and 1 mechanical field (6' x 30'). There are 4 electrical fields being 6' x 30'.
- Collecting plates are rapped by MIGI rappers and the HV wires by electric vibrators.
- The HV electrodes are plain round wire (0.109" dia.) with 25# weights per each wire.
- There are a total of 12 T-R sets on the ESP.



## *The Little Precipitator that Could*



## The LPTC, Collecting System Data

<b>Table C: Collecting System</b>	<b>Units</b>	<b>LPTC</b>	<b>Score</b>
<b>No. Mechanical Fields</b>	<b>No.</b>	<b>3</b>	<b>&gt;3</b>
<b>No. Electrical Fields</b>	<b>No.</b>	<b>4</b>	<b>&gt;3</b>
<b>Mechanical Fields Length</b>	<b>Ft.</b>	<b>9,9,6</b>	
<b>Total Treatment Lenth</b>	<b>Ft.</b>	<b>24</b>	
<b>Collecting Plate Height</b>	<b>Ft.</b>	<b>30</b>	
<b>Gas Passage Width</b>	<b>In.</b>	<b>9</b>	
<b>Number gas Passages per Chamber</b>	<b>No.</b>	<b>40</b>	
<b>Aspect Ratio</b>	<b>Ft./Ft.</b>	<b>0.80</b>	<b>&gt; 1.0</b>
<b>Total Plate Area per Boiler</b>	<b>Ft<sup>2</sup></b>	<b>172,800</b>	
<b>Number of Plate Rappers</b>	<b>No.</b>	<b>96</b>	
<b>Type of Plate Rappers</b>		<b>MIGI</b>	
<b>Plate Area per Rapper</b>	<b>Ft<sup>2</sup></b>	<b>1,800</b>	<b>&lt; 1500</b>
<b>Plate Area per T-R Set</b>	<b>Ft<sup>2</sup></b>	<b>14,400</b>	<b>&lt;15000</b>

## Collecting System Data Comments

<u>Table D: Collecting System</u>	Units	LPTC	Score
No. Mechanical Fields	No.	3	>3
Aspect Ratio	Ft./Ft.	0.80	> 1.0
Plate Area per Rapper	Ft <sup>2</sup>	1,800	< 1500
Plate Area per T-R Set	Ft <sup>2</sup>	14,400	<15000

- New ESP designs utilize four and often times five collecting fields
- The aspect ratio (treatment length/plate height) is poor. Modern day standards utilize 1.0 or greater
- The collecting plate rapping density is challenged. Even though it is close to the rule of thumb of < 1500 sq. ft. per rapper, the way that the Buell ESP suspends and spreads its collecting plates, makes it suspect.
- Finally, the collecting area energized by T-R sets is very good. Originally this ESP only had 4 T-R sets with a density of 43,200 ft<sup>2</sup>/TR, a gross mismatch and it showed in the ESP performance. 8 T-R sets were added in the 90's

## *HV System Data Comments*

<u>Table E: Corona Electrodes</u>	Units	LPTC	Score
Type		Round	
Weight per Electrode (if Applicable)	Lb.	25/30	>0.75lb/ft
Electrodes per T-R Set	No.	320	
Total Length of Electrodes/T-R Set	Ft.	9,600	
Rappers/T-R Set	No.	1	
Length of Electrode per Rapper	Ft/Rapper	4,800	< 2400
Total number of HV Rappers	No.	24	

- There is too much lineal feet of wire per electric vibrator. One vibrator is used to clean a wire frame 30' wide. All modern designs would use 2 vibrators for a frame of that width.
- The 25 lb. weights used are ideal in terms of weight per foot, for this installation.

## T-R Set Ratings - Analysis

<b>Table F: T-R Set Data</b>		<b>Units</b>	<b>LPTC</b>	<b>Score</b>
Field _	Secondary Rating	KV/mA	1:45/500	
Field _	Secondary Rating	KV/mA	2: 45/750	
Field _	Secondary Rating	KV/mA	3: 45/1000	
Field _	Secondary Rating	KV/mA	4: 45/1000	
Field _	Design Current Density	uA/Ft <sup>2</sup>	34.7	> 30
Field _	Design Current Density	uA/Ft <sup>2</sup>	52.1	> 40
Field _	Design Current Density	uA/Ft <sup>2</sup>	69.4	> 50
Field _	Design Current Density	uA/Ft <sup>2</sup>	69.4	> 60

- All the T-R sets are sized conventionally with a 45KVDC average rating, common for 9" gas passage widths. The 1<sup>st</sup> and 2<sup>nd</sup> fields of this ESP run above the 45KV rating (47 – 51KVDCAvg). If the ESP is rebuilt, T-R sets of a higher voltage rating should be considered.
- All of the T-R sets are properly sized with a graded milliamp rating from inlet to outlet of the ESP (suitable for applications of dust with a resistivity of  $< 5 \times 10^{10}$  ohm-cm).

T-R LOCATION UNITS	T-R NAME	AREA ENRGZ'D FT <sup>2</sup>	GAS PASS WIDTH IN.	NORMAL CURRENT DENSITY	SECONDARY CURRENT mA	CURRENT DENSITY uA/FT <sup>2</sup>	SECONDARY VOLTAGE KV	SECONDARY POWER KW	SPARK RATE SPM
1A	A NORTH	14,400	9	10 TO 20	356	24.7	61	21.7	22
1B	A CENTR	14,400	9		273	19.0	54	14.7	61
1C	A SOUTH	14,400	9		234	16.3	57	13.3	62
2A	B NORTH	14,400	9	20 TO 30	756	52.5	51	38.6	0
2B	B CENTR	14,400	9		700	48.6	50	35.0	0
2C	B SOUTH	14,400	9		687	47.7	48	33.0	10
3A	C NORTH	14,400	9	30 TO 50	1006	69.9	37	37.2	0
3B	C CENTR	14,400	9		1007	69.9	40	40.3	0
3C	C SOUTH	14,400	9		1005	69.8	39	39.2	0
4A	D NORTH	14,400	9	50 TO 70	1006	69.9	38	38.2	0
4B	D CENTR	14,400	9		1006	69.9	40	40.2	0
4C	D SOUTH	14,400	9		1007	69.9	40	40.3	0
<b>TOTAL</b>		<b>172800</b>			<b>9043</b>			<b>391.773</b>	<b>155</b>

SHOW T-R NAMES IN LOCATION, HERE:						W/ FT <sup>2</sup>	2.27	
						W/1000ACFM	363.6	
<b>GAS FLOW</b> 	<b>A</b>	1	2	3	4	GAS PSG	<b>TOTAL DENSITY</b>	<b>52.3</b>
		AN	BN	CN	DN	40@9"		
	<b>B</b>	AC	BC	CC	DC	40@9"	<b>TEST</b>	<b>#/MMBtu</b>
		AS	BS	CS	DS	40@9"		
	<b>C</b>	500	750	1000	1000		<b>TOTAL</b>	<b>0.0098</b>
<b>TR SIZE</b>	6X30'	6X30'	6X30'	6X30'		<b>FLTERABLE</b>		
<b>FIELD DIMENSION</b>	6X30'	6X30'	6X30'	6X30'		<b>CNDNSBLE</b>		

ELECTRICAL REVIEW

## ESP Electrical Performance Review

<u>Table G: ESP Performance Data</u>	Units	TLPC	Score
Total ESP Power	KW	392	
ESP Power /Gas Volume	W/1000 ACFM	370	> 450
ESP Power /Plate Area	W/Ft <sup>2</sup>	2.27	
ESP Average Current Density	uA/Ft <sup>2</sup>	52	> 35

- The relationship between corona current density (uA/ft<sup>2</sup>), power density(watts/ft<sup>2</sup>), specific corona power (watts/1000acfm), SCA, and ESP collection efficiency have been well researched over the years.
- This ESP exhibited good total power, good average watt density, and very good average corona current density. However, the specific corona power was less than one would expect to meet the MATS requirements.
- That low corona power, coupled with high total power and watt densities is resultant from this ESP's low SCA
- As an example, take an ESP with a watt density of 2.0 watts/ft<sup>2</sup> and an SCA of 200 (ft<sup>2</sup>/1000 acfm), then the specific corona power would be 400 watts/1000 acfm. If the SCA was twice as big, at 400, that same watt density would produce a specific corona power of 800!

## *Total specific corona power drives ESP Performance*

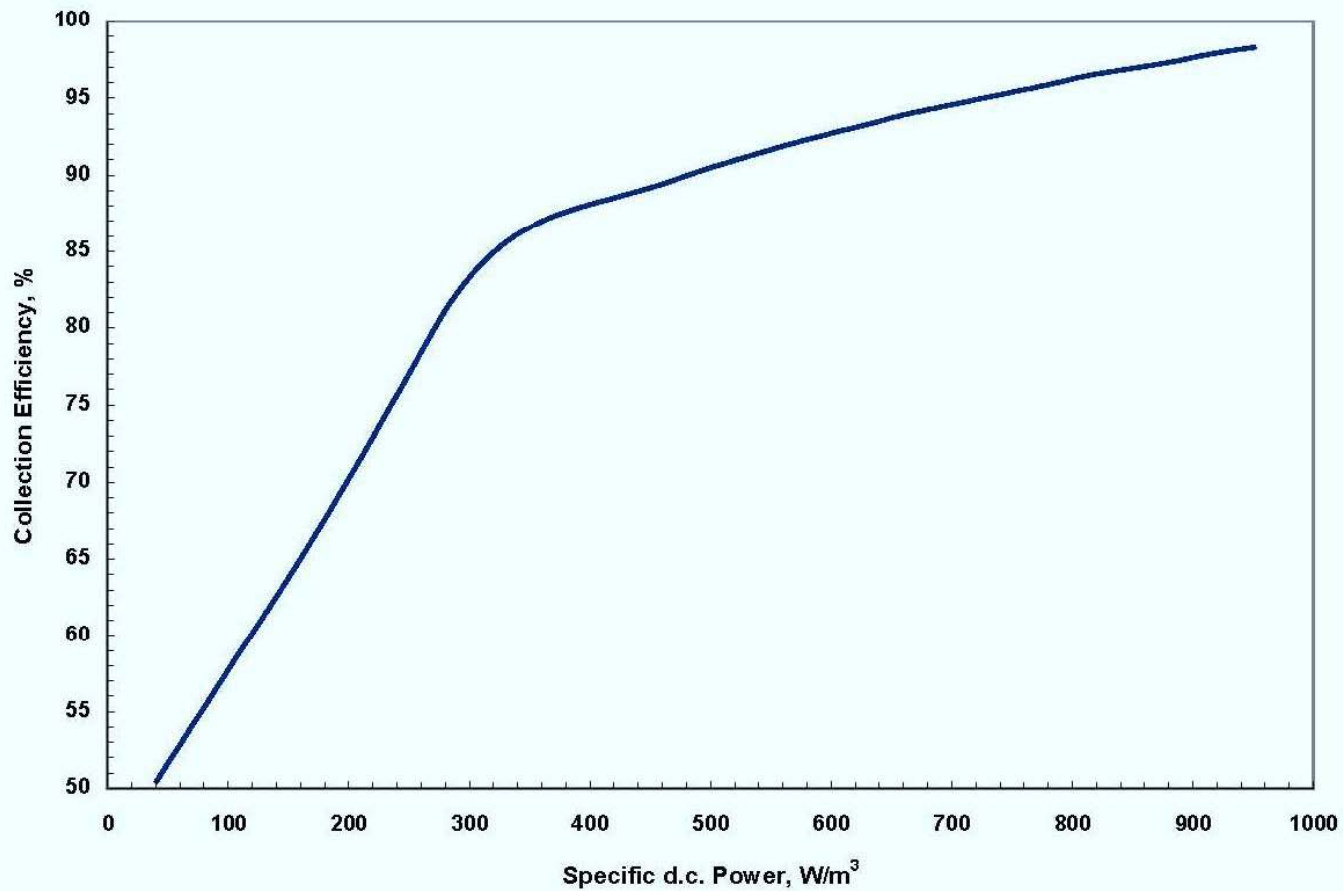


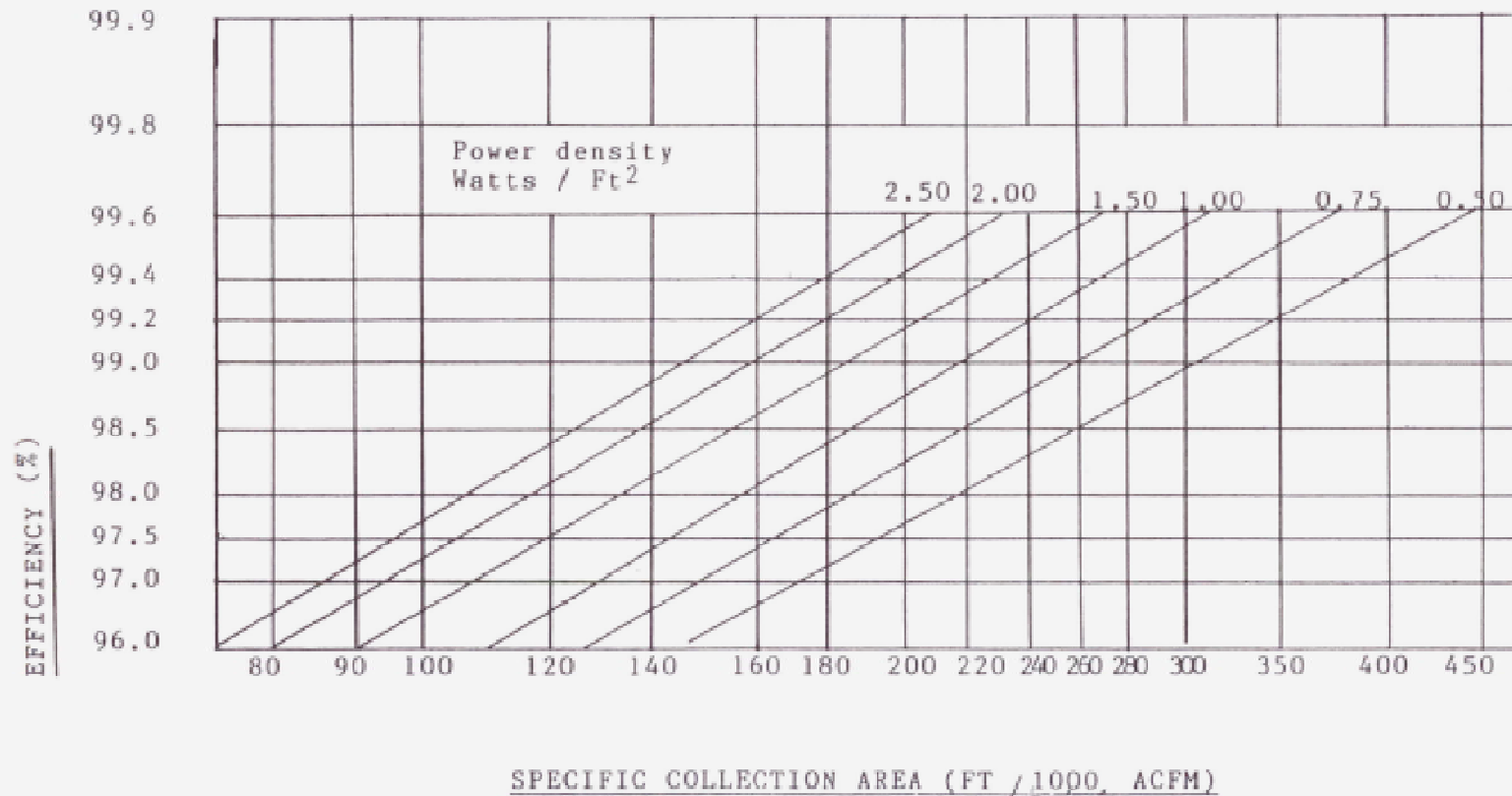
Figure 4-6. Effect of specific power absorption on ESP efficiency.

## ESP Performance Data Review

<u>Table H: ESP Performance Data</u>	Units	TLPC	Score
Aspect Ratio	Ft/Ft	0.80	> 1.0
Treatment Velocity	Ft/Sec	6.5	< 5.0
Treatment Time	Seconds	3.7	>7.0
Specific Collecting Area <sub>g</sub>		163	> 300

- The treatment velocity used in new ESP designs is 4.0 ft/sec or less.
- This usually assures an adequate “treatment time” for the dust particles to be in the ESP for collection. The velocity in this unit is very high. This, coupled with its very poor aspect ratio (0.80), should be a candidate for higher emissions than the recent tests reveal.
- High velocities also contribute to rapping re-entrainment and gas sneakage problems.
- The target 300 SCA is conservatively based on the resistivity of the dust being at  $< 5 \times 10^{10}$  ohm-cm and a targeted PM emissions limit of 0.020 #/MMBtu (safety factor).

# ESP Performance as a Function of Power Density and SCA for a PC Boiler by Grieco



## Recent PM Testing

<b>Table I: Emissions Data</b>	<b>Units</b>	<b>LPTC</b>	<b>LPTC</b>	<b>LPTC</b>	<b>LPTC</b>
<b>Last Stack Test ( Average of Tests)</b>	<b>Test Date</b>	<b>6/15/2010</b>	<b>9/26/2011</b>	<b>10/6/2011</b>	<b>10/11/2011</b>
<b>Gross MW</b>	<b>MW</b>	<b>305 MWG</b>	<b>300 MWG</b>	<b>301 MWG</b>	<b>300 MWG</b>
<b>Stack Test Volume</b>	<b>ACFM</b>	<b>1,059,298</b>	<b>1,077,953</b>	<b>1,069,938</b>	<b>1,073,470</b>
<b>Stack Temperature</b>	<b>°F</b>	<b>295.6</b>	<b>299.6</b>	<b>293.8</b>	<b>296.5</b>
<b>Stack Test Moisture by Vol.</b>	<b>%</b>	<b>12.2</b>	<b>11.1</b>	<b>12.8</b>	<b>12.1</b>
<b>Total Filterable PM</b>	<b>#/MMBtu</b>	<b>0.0285</b>	<b>0.0114</b>	<b>0.0135</b>	<b>0.010</b>
<b>Test Stack Opacity</b>	<b>%</b>	<b>7.0</b>	<b>6.8</b>	<b>7.9</b>	<b>7.5</b>

- According to the plant, all PM tests were done with the same coal blends
- The 6/15/10 testing was done with the usual ash conditioning of 24ppm SO<sub>3</sub> injection. Unfortunately, only the results were available and no indication of the ESP power levels at the time of this test.
- The 2011 testing was done with a proprietary non-SO<sub>3</sub> based flyash conditioning technique, in order to prevent the adverse impact of SO<sub>3</sub> on activated carbon injection trials, at the time.
- Two things are immediately apparent: 1) the 60% reduction in mass emissions and 2) the disparity between mass emissions and opacity

## PM Testing – Why the Difference?

<u>Table I: Emissions Data</u>	Units	LPTC	LPTC	LPTC	LPTC
Last Stack Test ( Average of Tests)	Test Date	6/15/2010	9/26/2011	10/6/2011	10/11/2011
Gross MW	MW	305 MWG	300 MWG	301 MWG	300 MWG
Stack Test Volume	ACFM	1,059,298	1,077,953	1,069,938	1,073,470
Stack Temperature	°F	295.6	299.6	293.8	296.5
Stack Test Moisture by Vol.	%	12.2	11.1	12.8	12.1
Total Filterable PM	#/MMBtu	0.0285	0.0114	0.0135	0.010
Test Stack Opacity	%	7.0	6.8	7.9	7.5

- The plant commented:
  - The boiler had been tuned up
  - The ESP had been cleaned prior to 2011 testing
  - Sections of tubular air-heater had been replaced
  - The ESP has new AVC's

## PM Testing – Why the Difference?

<b>Table I: Emissions Data</b>		<b>Units</b>	<b>LPTC</b>	<b>LPTC</b>	<b>LPTC</b>	<b>LPTC</b>
<b>Last Stack Test ( Average of Tests)</b>	<b>Test Date</b>		<b>6/15/2010</b>	<b>9/26/2011</b>	<b>10/6/2011</b>	<b>10/11/2011</b>
<b>Gross MW</b>	<b>MW</b>		<b>305 MWG</b>	<b>300 MWG</b>	<b>301 MWG</b>	<b>300 MWG</b>
<b>Stack Test Volume</b>	<b>ACFM</b>		<b>1,059,298</b>	<b>1,077,953</b>	<b>1,069,938</b>	<b>1,073,470</b>
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<b>Total Filterable PM</b>	<b>#/MMBtu</b>		<b>0.0285</b>	<b>0.0114</b>	<b>0.0135</b>	<b>0.010</b>
<b>Test Stack Opacity</b>	<b>%</b>		<b>7.0</b>	<b>6.8</b>	<b>7.9</b>	<b>7.5</b>

- What also could be happening:
  - The 2010 test may have had a greater quantity of “large carbon” carryover common to cyclone boilers. One can have high mass emissions from large PM, which does not affect opacity very much.
  - That the Method 5 PM test, itself, can contribute a considerable positive bias for a flue gas with a high SO<sub>3</sub> concentration. This bias could be resultant from the test method’s utilization of a 250<sup>0</sup> F temperature for the filter probe, which can be below the acid dew point. The filter would then capture and weigh the condensed SO<sub>3</sub>

## The Bottom Line

<u>Table C: Emissions Data</u>	Units	LPTC	LPTC	LPTC	LPTC
Last Stack Test ( Average of Tests)	Test Date	6/15/2010	9/26/2011	10/6/2011	10/11/2011
Gross MW	MW	305 MWG	300 MWG	301 MWG	300 MWG
Stack Test Volume	ACFM	1,059,298	1,077,953	1,069,938	1,073,470
Stack Temperature	°F	295.6	299.6	293.8	296.5
Stack Test Moisture by Vol.	%	12.2	11.1	12.8	12.1
Total Filterable PM	#/MMBtu	0.0285	0.0114	0.0135	0.010
Test Stack Opacity	%	7.0	6.8	7.9	7.5

- These PM numbers far exceeded our expectations. For a relatively small SCA of 163, its performance was an outlier. (Efficiency 99.5 vs 98.8%)
- In our research of previous studies that had been done on the unit, we came across one by Herb Hall (the Dean of Electrostatic Precipitation), from 1989 . His opinion, after a very detailed analysis, was that you would need a 50% larger ESP, to achieve the numbers obtained in 2011 testing!
- And so it aptly became, **“The Little Precipitator that Could.”**



***Questions?***

*Thank you.*

