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February 20, 2009



Mr. Terry O'Clair
Director, Division of Air Quality
North Dakota Department of Health
918 E. Divide Avenue, 2nd Fl
Bismarck, ND 58501-1947

RE: Supplemental information for the North Dakota Department of Health's Best Available Control Technology Determination for Control of Nitrogen Oxides for M.R. Young Station Units 1 and 2, dated June 2008

Dear Mr. O'Clair:

In response to the Department's request for additional information concerning the use of Low Dust SCRs and Tail End SCRs at Milton R. Young Station, please find enclosed the report titled "Supplemental Information for Consideration Regarding NOx BACT for M.R. Young Units 1 and 2: Technical Feasibility Issues for TESCR or LDSCR Retrofit, February 20, 2009".

Minnkota continues to believe the NDDH's preliminary BACT determination dated June 2008 to be correct and appropriate.

Should you have any questions concerning this submittal, please contact me at 701-795-4221.

Sincerely,

MINNKOTA POWER COOPERATIVE, INC.

John T. Graves, P.E.
Environmental Manager

C: David Sogard

**Supplemental Information for Consideration by NDDH
Regarding NO_x BACT for M.R. Young Units 1 and 2:
Technical Feasibility Issues for TESCO or LDSCR Retrofit**

**prepared for
Minnkota Power Cooperative, Inc.
And
Square Butte Electric Cooperative**

February 20, 2009

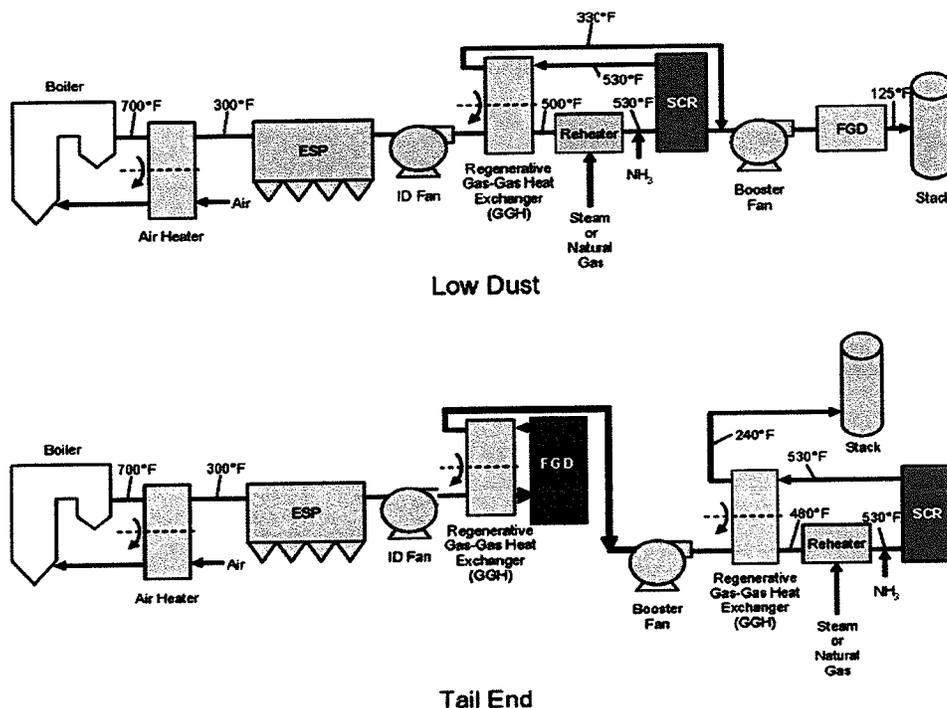
**prepared by
Burns & McDonnell Engineering Company, Inc.
Kansas City, Missouri
and
Steve Benson, PhD
Department of Chemical Engineering,
University of North Dakota**

Project No. 31777

Supplemental Information for Consideration Regarding NOx BACT for M.R. Young Units 1 and 2: Technical Feasibility Issues for TESCR or LDSCR Retrofit February 20, 2009

1. Purpose

Burns & McDonnell (B&McD), along with Steve Benson of the Department of Chemical Engineering at the University of North Dakota¹, have reviewed the technical literature provided by the North Dakota Department of Health (NDDH) regarding submicron particle collection and penetration for dry electrostatic precipitators (ESPs), and have prepared this document in response. The information and commentary provided herein are being submitted to NDDH for consideration relative to selective catalytic reduction (SCR) technology infeasibility for control of nitrogen oxides emitted from Milton R. Young Station Units 1 and 2. Issues related to the technical infeasibility of SCRs located in both the low-dust configuration (LDSCR) and the tail-end configuration (TESCR) are addressed. [Refer to the basic schematic diagrams below].



¹ formerly employed by Energy & Environmental Research Center (EERC) of the University of North Dakota.

We continue to believe that the administrative record fully supports a finding by the NDDH that separated over-fire air (SOFA) in conjunction with selective non-catalytic reduction (SNCR) technology is Best Available Control Technology (BACT) for NO_x control for electric generating units that utilize cyclone burners firing North Dakota lignite.

2. Scope

The following sections address specific topics pertaining to the NDDH's Preliminary NO_x BACT Determination for Nitrogen Oxides for Milton R. Young Station Units 1 and 2, dated June 2008 (NDDH, 2008)

- Significance of submicron aerosol particle removal by ESPs and wet FGD
- Evaluation of submicron particle penetration data provided by NDDH
- Sodium-rich aerosol formation and penetration through ESP and FGD at M. R. Young Station firing North Dakota lignite
 - Form of sodium in Center lignite
 - Vaporization of sodium in the high temperature cyclones' combustion process
 - Condensation of sodium and concentrating in the submicron size fraction
 - Electrostatic precipitator collection efficiency
 - Aerosol capture efficiency in scrubbers
 - Powerspan testing at MRYS
 - MRYS sulfate aerosol sampling
- Determination of Sodium Loading Adversely Affecting SCR Catalyst Performance
- Alkali Aerosol Loading and Catalyst Deactivation
- Experience of ESP/FGD equipped utility plants co-firing biomass and coal with TESCR
- Relevance of recent TESCR investigations at We Energies' South Oak Creek Station
- Relevance of ongoing LDSCR installation at We Energies' South Oak Creek Station
- Relevance of existing LDSCR installation at PSEG Mercer Station
- Additional technical feasibility issues for TESCR at MRYS
- Summary and Conclusions

3. Significance of Submicron Aerosol Particle Removal by ESPs and Wet FGD

The removal percentage of submicron or aerosol particles by an ESP or any other device is not important. The key is not what is removed, but rather the quantity that is not removed. The amount (mass and number) of submicron and ultrafine particles, as well as the speciation of the particles which pass through the ESP, are extremely important. These particles have the following detrimental characteristics:

- Condensed vapor phase species concentrate in the less than 1 μm size fraction and are in the range of particle sizes where ESPs and wet flue gas desulfurization systems (FGDs) are ineffective in capturing them
- Small particles that can penetrate deep into catalyst pores
- Highly reactive, because of chemistry [rich in sodium (Na), potassium (K), sulfur (S), phosphorus (P)], which results in poisoning sites
- Highly reactive, because of physical characteristics – high surface area can react with gas phase species, which results in blinding of pores
- Highly concentrated because of the removal of larger particles by cyclone and air pollution control devices
- Highly concentrated aerosols (not diluted by large particles) that upon accumulation can efficiently bond together causing catalyst blinding and are available to poison active sites

4. Evaluation of Submicron Particle Penetration Data provided by NDDH

The NDDH provided publications on the efficiency of ESPs and scrubbers to remove particulate as well as penetration of aerosol particles through the devices. The following are some of the key conclusions that can be drawn from the review of the information described in these papers. The information provided indicates poor collection efficiency of submicron particles:

- The particulate collection efficiencies for the coarse fraction particles or particles larger than 1 to 5 μm in ESPs are generally very good (99.9%).

- For particles less than 1 μm , the collection efficiency drops off significantly.
- Particles in the finer size fractions are largely composed of condensed vapor phase species such as sodium, potassium, chlorine (Cl), and sulfur.
- Higher combustion temperatures result in more vaporization and increased levels of submicron particles.
- Emission rates downstream of ESPs described in the reports range from 4,500 to 50,000 $\mu\text{g}/\text{Nm}^3$. The particulate are dominated by aerosols rich in sodium and potassium.
NOTE: The level of 22,500 $\mu\text{g}/\text{Nm}^3$ of sodium and potassium rich fly ash derived from biomass resulted in catalyst deactivation of 40 % in 1500 hours (Kling and others, 2007).

Specific observations and/or comments on each of the documents provided by NDDH are presented below:

Mohr, M., Ylatalo, S., Klippel, N., Kauppinen, E.I., Riccius, O., and Burtscher, H., Submicron Fly Ash Penetration through Electrostatic Precipitators at Two Coal Power Plants, Aerosol Science and Technology 24:191-204(1996)

Measurement of the size distribution of fine particulate (diameter less than 0.5 μm) at the inlet and outlet of the ESP for two full scale pulverized coal fired power plants was conducted. The coals fired consisted of high volatile bituminous coals from South Africa and Columbia. The characteristics of these coals are summarized in Table 1. The analysis indicates very low levels of sodium as well as other alkali and alkaline earth elements [K, calcium (Ca), and magnesium (Mg)]. The potential for formation of alkali rich aerosols from these coals is extremely small because of the form of the alkali and abundance.

Table 1. Coal analysis (Mohr and others, 1996)

COAL		South	Colombia	South
Country		Africa	Eldorado	Africa
Coal field		Klein		Klein
Location of burning		Kopie	Plant A	Kopie
Date		Plant A	17.5.94	Plant B
		9.5.94		11.8.93
Proximate analysis				
Total moisture	%	9.9	13.5	7.4
dry weight bases				
Ash	%	17.1	10.2	16.2
Volatile matter	%	20.7	35.5	23
fixed carbon	%	62.2	54.2	60.9
Gross calorific value	MJ/kg	27.42	29.99	27.34
Ultimate analysis				
Carbon	%	70.3	73.4	68.4
Hydrogen	%	3.4	4.6	1.5
Nitrogen	%	1.7	1.5	3.5
Oxygen	%	7	9.4	9.9
Sulfur	%	0.43	0.81	0.5
Coal ash				
P ₂ O ₅	%	1.2	0.3	1.2
SiO ₂	%	45.3	55.7	47.7
Fe ₂ O ₃	%	3.5	7.3	3.1
Al ₂ O ₃	%	31.4	21.0	33.2
TiO ₂	%	1.6	0.9	1.7
CaO	%	7.3	4.1	6.2
MgO	%	1.7	2.1	1.4
SO ₃	%	5.4	3.1	4.8
K ₂ O	%	1.0	2.1	0.7
Na ₂ O	%	0.3	0.6	0.2
Li ₂ O	%	0.0	0.0	0.0

By comparison, Table 2 summarizes the average lignite properties relevant to MRYS. It can be seen that the characteristics of the MRYS coals are very different and will produce significantly different size distributions of ash than the coals fired in the plants reported by Mohr and others, 1996.

Table 2. Average Center lignite and ash composition (moisture, ash, sulfur, and heating value expressed on an as-received basis; and ash composition expressed as weight percent equivalent oxide of the ash).

	Moisture, %	Ash, %	Sulfur, %	Btu/lb	Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	MgO	P ₂ O ₅	K ₂ O	SiO ₂	Na ₂ O	SO ₃
Average	37.13	9.64	0.98	6578	11.68	0.52	13.15	8.90	3.99	0.12	1.33	36.04	4.40	18.39

This testing has little relevance to the collection of ash in the MRY boilers for two primary reasons. The first is the firing type. The boilers are pulverized coal (PC)-fired and partitioning to the finer ash fraction will be much lower than that observed for cyclone-fired boilers. The

second reason is coal type. The coals tested are bituminous coals. The ash forming components in the bituminous coals are mineral grains with no organically associated elements (Na, K, Ca and Mg). The fraction of the elements in an easily vaporizable form is much lower in the bituminous coals producing lower levels of ash in the smaller sized fractions.

Nobrega, S.W., Falaguasta, M.C.R., and Coury, J.R., A Study of a Wire-Plate Electrostatic Precipitator Operating in the Removal of Poly dispersed Particles, Brazilian Journal of Chemical Engineering, Vol 21, No. 02, pp 273-284, April-June 2004.

This paper is a laboratory and computer modeling effort that examined the performance of ESPs. The precipitators tested were small scale laboratory systems. A phosphatic concentrate was used as particulate. Computational models for predicting fine particle removal in ESPs were improved. However, the relationship to particulate collection from coal fired power systems is small.

Power Station Emissions Handbook, Cooperative Research Centre for Coal in Sustainable Development, http://www.ddsd.biz/PSE_Handbook/5/6/5/index.cfm accessed 11/24/2008.

This document states:

“Wet scrubbers can remove more than 90% for particles with diameters above 10 microns. Efficiencies for smaller particles will be significantly lower.”

“The size distribution of the dust influences the overall ESP collection efficiency. Particles in the range of 0.1 to 1.0 μm are the most difficult for an ESP to collect. “

“ESP collection efficiency is particularly affected by several factors including coal ash resistivity, gas temperature, chemical composition and particle size distribution (Wu 2001).”

There is no discussion on fly ash types that are collected. Only general data is provided. Application to high sodium lignite derived coal ashes is not apparent from the website.

This website states:

“Precipitator collection efficiencies will be somewhat lower for particles with diameters near 0.3 microns. The reason for a minimum in collection efficiency for 0.3 micron particles is that both particle charge and the resistance of the gas to particle motion both increase with particle size. Near 0.3 micron, the particle charge is low enough and the resistance to particle motion is high enough that particles are collected relatively poorly.”

These conclusions indicate that aerosols can penetrate through ESPs.

Lind, T., Hokkinen, J., and Jokiniemi, J.K., Saarikoski, S., and Hillamo, R., Electrostatic Precipitator Collection efficiency and Trace Element Emissions from Co-Combustion of Biomass and Recovered Fuel in Fluidized-bed Combustion, Environmental Science and Technology, 2003, 37, 2842-2846.

This paper describes the removal efficiency of ash particles produced in a 66 megawatt (MW) biomass-fired bubbling bed fluidized bed combustion (FBC) system. Fluidized bed combustion systems operate at lower temperatures (1400 to 1600 °F) than conventional pulverized coal-fired or cyclone-fired utility boilers. The bed material in the FBC was sand. The fuel was mixture of peat and wood wastes. Fluidized bed systems typically have significant levels of entrained ash particles that provide sites for condensation of vaporized species. The particles that penetrated the ESP were found to contain mostly alkali salts (Na, K, Cl, and SO₄). The quantity of materials penetrating the ESP was 4.5 to 9 mg/Nm³ (4,500 to 9,000 µg/Nm³).

The 2003 paper by Lind references her earlier work on ash formation mechanisms (Lind, and others, 2000). This paper describes in detail the mechanisms of formation of the aerosol particles and that they are enriched in alkali salts (Na, K).

Ohlstrom, M., Jokiniemi, J., Hokkinen, J., Makkonen, P., and Tissari, J., Combating Particulate Emissions in Energy Generation and Industry, Tekes, VTT Technical Research Centre of Finland, 2006.

This paper also describes the concentrating of vaporized elements such as sodium and potassium in the fine (less than 1 μm) size fraction. The authors also state “higher combustion temperatures typically increase the amount of fine particle released.” In addition, they discuss the fact that “Electrostatic precipitators are at their least efficient when handling particle sizes between 0.1 μm to 1 μm .” They indicated in Table 8 on pg 29 of the report that the emission rates ranged from 15 to 50 mg/Nm^3 (15,000 to 50,000 $\mu\text{g}/\text{Nm}^3$) from the ESP. This paper also shows that scrubbers are extremely ineffective in removing aerosols.

5. Sodium-Rich Aerosol Formation and Penetration Through ESP and FGD at M. R. Young Station Firing North Dakota Lignite

As described above, the fly ash penetration derived from the preceding described literature is not fully relevant to MRYS due to the significant differences in the sodium content of the fuels fired and the differences in the fuel firing mechanism employed in the plants tested. The following discussion will briefly review the following topics:

- Form of sodium in Center lignite
- Vaporization of sodium in the high temperature cyclones’ combustion process
- Condensation of sodium and concentrating in the submicron size fraction
- Electrostatic precipitator collection efficiency for fine particulate and relationship to ash produced from Center lignite
- Aerosol capture efficiency in scrubbers
- Powerspan testing at MRYS
- MRYS sulfate aerosol sampling.

Form of Sodium in Center Lignite

Sodium is associated with the organic matrix in Center lignite. That means the sodium is atomically dispersed in the organic matrix. The sodium is associated with a carboxylic acid groups (ion exchange sites). The carboxylic acid groups act as bonding sites for various

elements such as Ba, Ca, Mg, and Sr along with minor amounts of K. Figure 1 illustrates the bonding of sodium to the organic fraction of the coal and the association of other coal impurities.

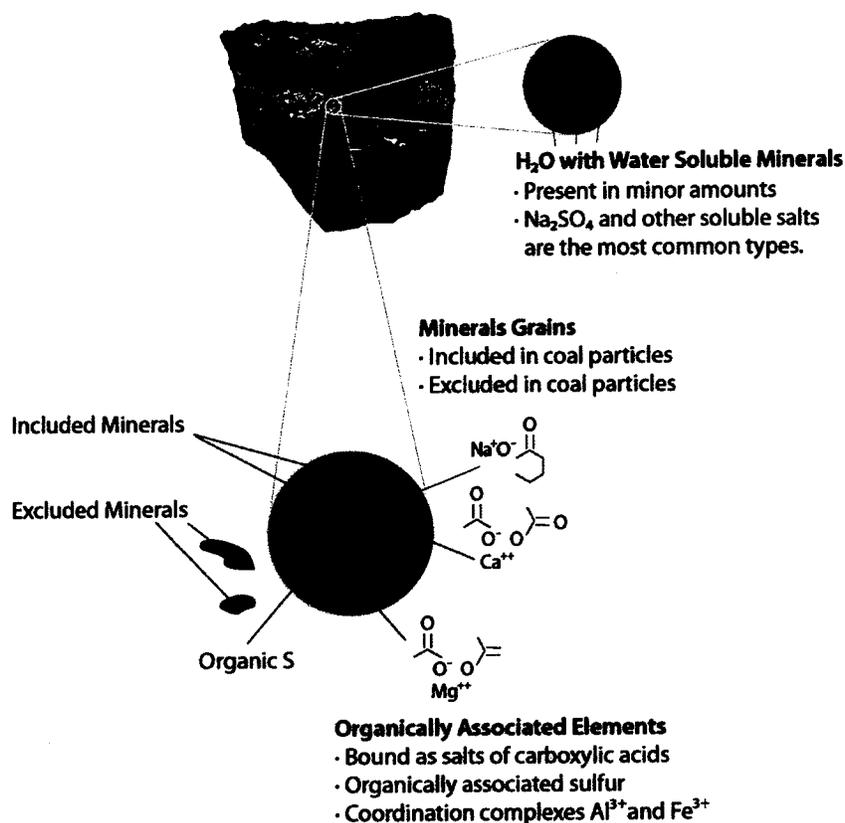


Figure 1. Form of sodium in coal (Benson and Laumb, 2008).

Vaporization of Sodium in the High Temperature Cyclones' Combustion Process

Sodium is a volatile element and is in the easily volatilized organic form in Center lignite and will be transformed into a gas upon combustion. The vaporization of sodium during the combustion of lignite is a very well known fact that has been examined by numerous investigators, including work conducted by MIT, CalTech, Sandia National Laboratory, National Energy Technology Laboratory, University of Utah, and others (see review by Lighty and others, 2000). For example, research conducted by Senior and others (2000) reported that relative to

other coals, North Dakota lignite produced more vaporized ash. The actual amount vaporized for ND lignite is double the level vaporized as compared to subbituminous and lignite coals from Montana as illustrated in Figure 2.

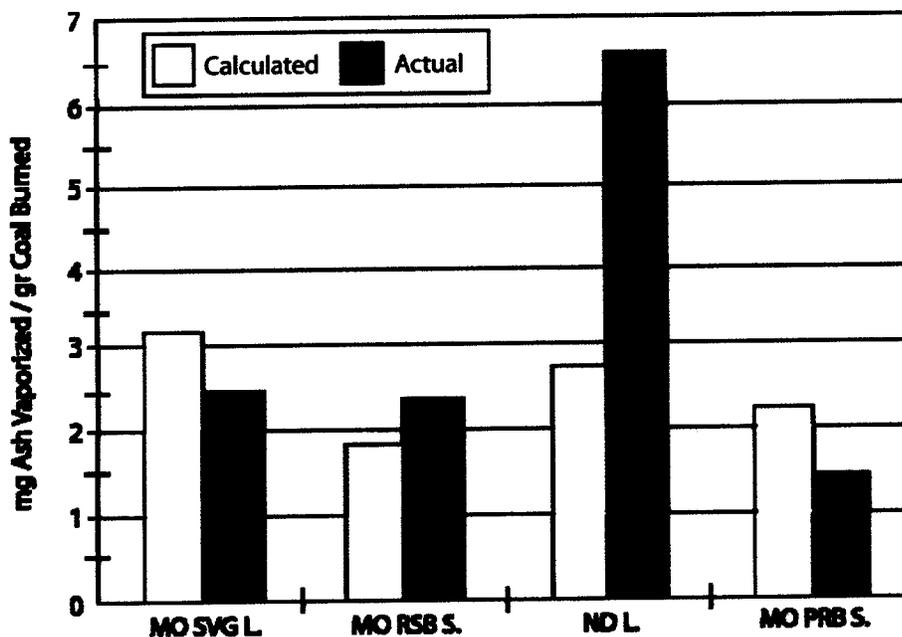


Figure 2. Ash vaporized during combustion of lignite and subbituminous coals (Senior and others, 2000).

Work conducted at the MRY plant related to the vaporization of sodium from a cyclone fired system is illustrated in Figure 3. The results show over two thirds of the sodium is not retained in the slag and is vaporized in the high sodium lower ash coals 1-3. In the low sodium high ash coals 4-5, very small amounts of the sodium was vaporized.

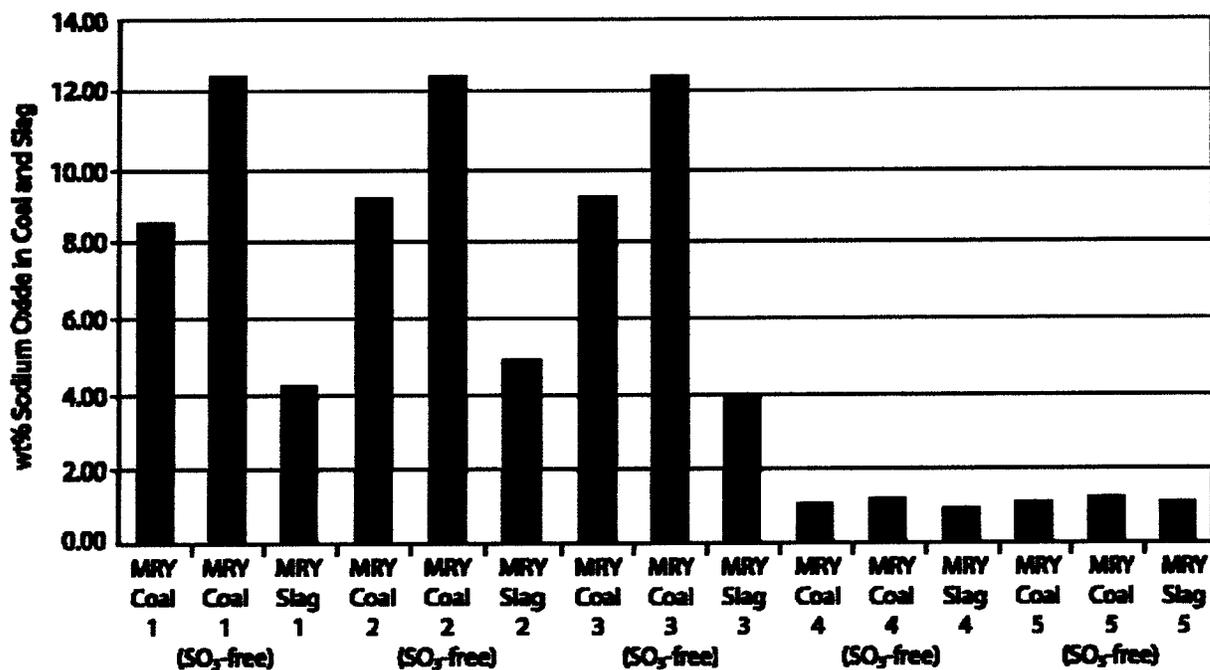


Figure 3. Comparison of sodium levels in Center lignite coal and slag samples.

Condensation of Sodium and Concentrating in the Submicron Size Fraction

EPA has evaluated the literature on particle formation during combustion and from other sources and incorporated it into an educational module that was found on the following website: (<http://www.epa.gov/apti/bces/module3/formation/formate.htm>). The classification of particle types shown by EPA is illustrated in Figure 4. The EPA classification is consistent with the review conducted by Lighty and others (2000). Vaporized species can condense heterogeneously on surfaces of other entrained coarse ash particles and can condense homogeneously to form the fine and ultrafine particles. The distribution of particles depicted in Figure 4 is shown on a “frequency percent particles by mass” basis. The number of particles versus size is also important. A comparison of the number of particles and particle size is summarized in Table 3. The number of aerosol particles is significant. These particles have high surface areas and are very reactive.

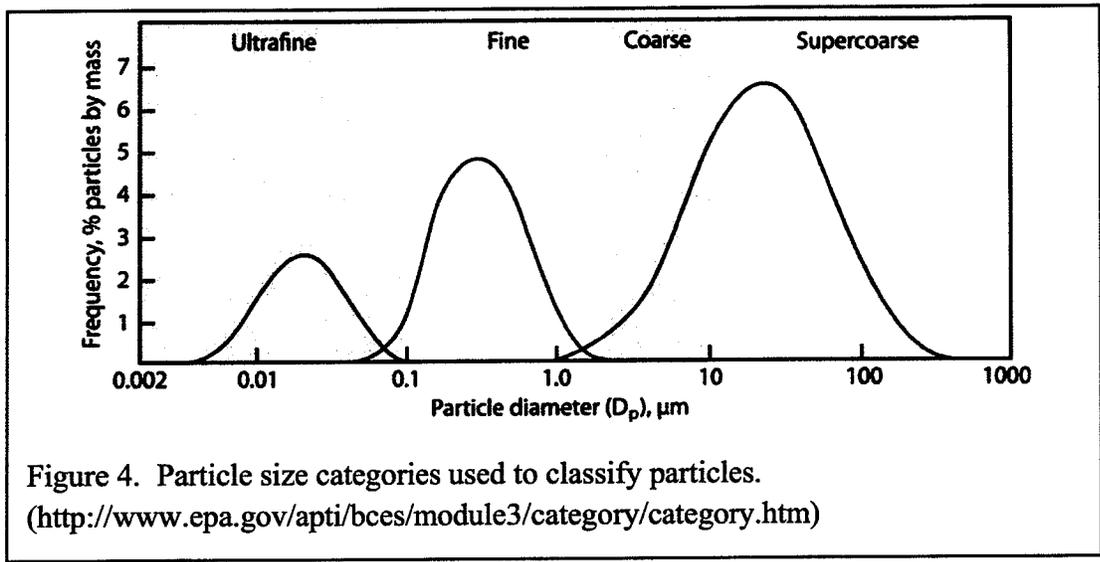


Figure 5 provides a comparison of the mass distribution and particle number distribution. As the particle size decreases the number of particles in the size fraction increases. In addition, as illustrated in Table 3, the surface area increases significantly with decreasing particle resulting in the opportunity for reactive gases such as sulfur oxides to react, forming sticky phases that bond particles together.

Table 3. Particle size, number of particles, and surface area¹
 (<http://www.epa.gov/apti/bces/module3/category/category.htm>)

Total Mass	Diameter of Particle (μm)	Number of Particles (Approx. in millions)	Total Surface Area	
			(cm ²)	(m ²)
1.0 gm	1,000	0.002	0	0.000
	100	2	600	0.00
	10	2,000	6,000	0.6
	1	2,000,000	60,000	6
	0.1	2,000,000,000	600,000	60

(1) Based on density of 1.0 gm/cm³

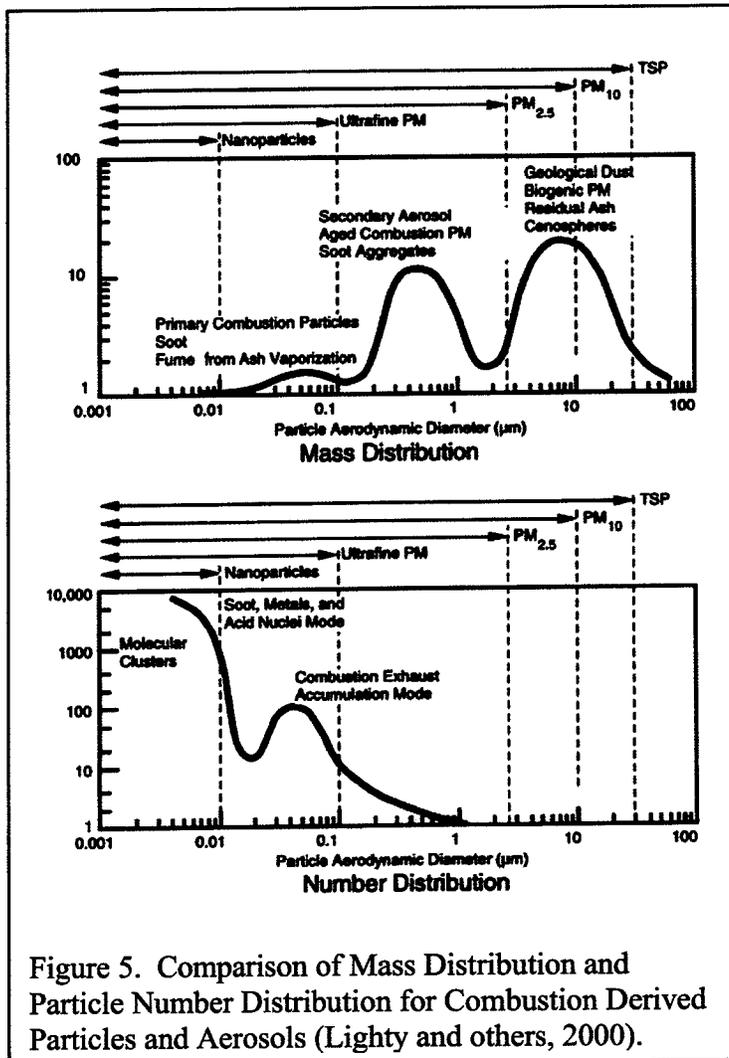


Figure 5. Comparison of Mass Distribution and Particle Number Distribution for Combustion Derived Particles and Aerosols (Lighty and others, 2000).

Particle size distributions for fly ash collected upstream and downstream of an ESP are illustrated in Figure 6. This work was conducted by Markowski and others (1980) specifically aimed at characterizing the submicron aerosol mode of fly ash formation. Figure 6B shows the penetration of fine particulate through the ESP.

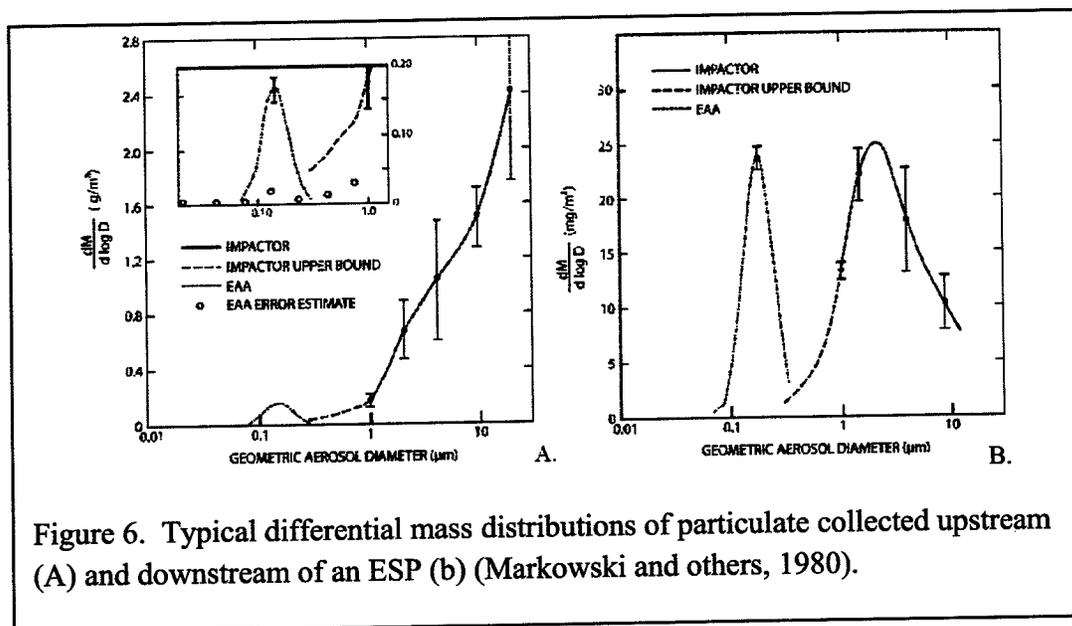
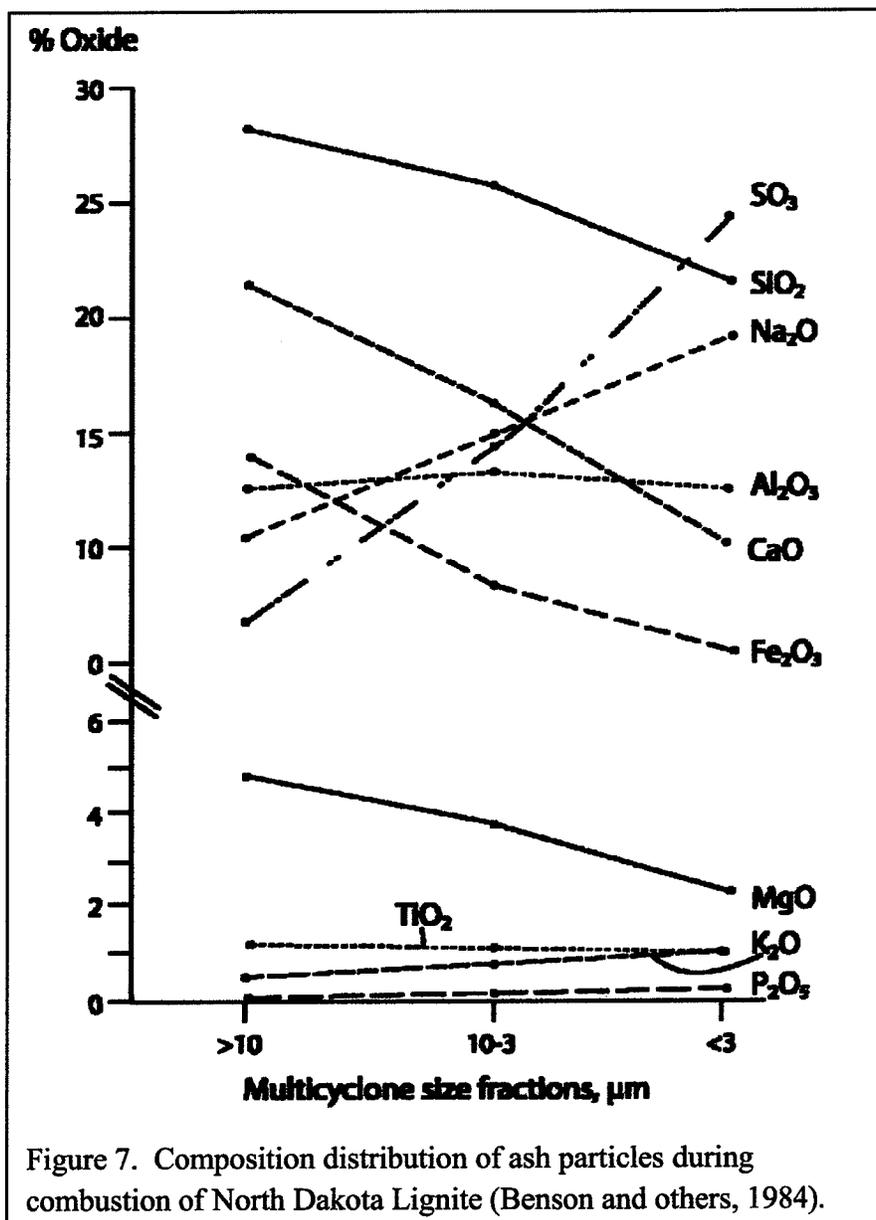


Figure 6. Typical differential mass distributions of particulate collected upstream (A) and downstream of an ESP (b) (Markowski and others, 1980).

Fly ash produced upon the combustion of high sodium lignites in a pulverized coal (PC) fired system shows significant enrichment of sodium in the smaller size fractions as shown in Figure 7. This figure illustrates the increase in the sodium content in the finer size fractions of ash as a result of firing high sodium lignite. The sodium and sulfur content of the less than 3 micrometer size fraction of the sampling train approached 20% Na₂O, and 25% SO₃. The form of the sodium is likely sodium oxide and sulfate.



Electrostatic Precipitator Collection Efficiency

The classical curve for ESP particle collection efficiency is shown in Figure 8. This curve is typical of well behaved ash materials that do not present significant problems in collection. The collection efficiency is very good for particles greater than 5 to 10 μm and the collection efficiency decreases with decreasing particle size, with a minimum collection efficiency between

0.2 to 2 μm in diameter. The collection efficiencies vary significantly because of particle size and composition.

Low collection efficiency for difficult to collect particles is between 0.1 to 1 μm in particle diameter. Figure 9 provides an illustration of the range of collection efficiencies. Based on EPA education modules (<http://www.epa.gov/apti/bces/module3/collect/collect.htm>), no air pollution control device shows high collection efficiency in this range (0.1 to 1.0 μm) due to inherent limitations of the collection devices and particle characteristics. The following mechanisms of particle capture are impacted by the size of the particles. The impact of these mechanisms are described

- Inertial impaction and interception
- Brownian diffusion
- Gravitational settling
- Electrostatic attraction
- Thermophoresis
- Diffusiophoresis

The EPA has indicated that based on a number of studies of actual “sources stationary sources generating high concentrations of particles in the 0.1 to 0.5 micrometer range may be an especially challenging control problem. ... The gap is most noticeable in wet scrubbers and electrostatic precipitators.” A generalized plot showing the range of collection efficiencies is shown in Figure 9. Overlaid on the diagram is the mass size distribution of particles collected downstream of the ESP wet FGD at the MRY plant (Markowski and others, 1983). This shows that ash produced in the MRY plant have a particle size that pass through the scrubber and that these particles are rich in sodium as previously shown in Figure 7.

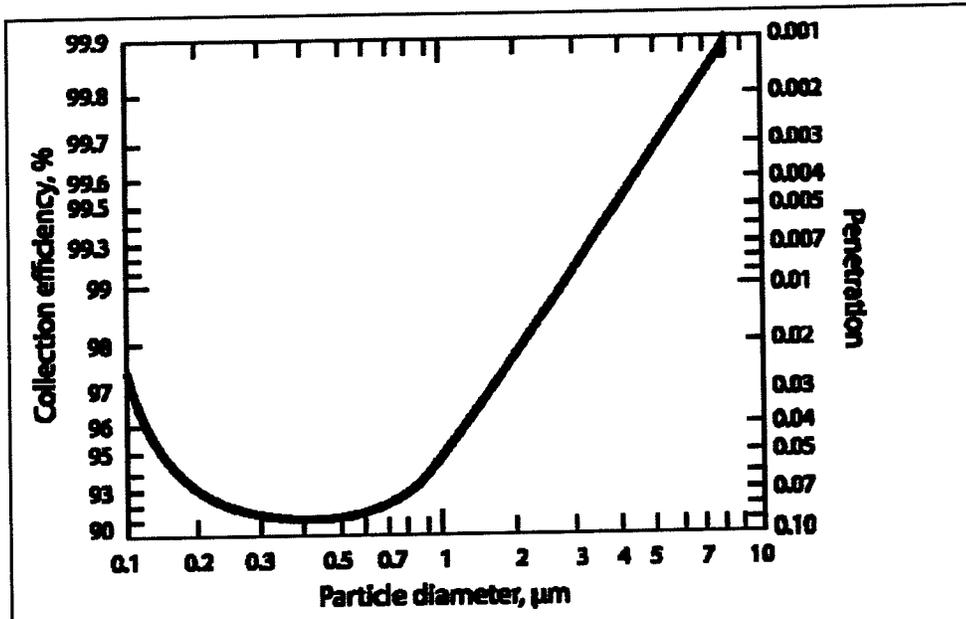


Figure 8. Typical ESP Collection efficiency curve for removal of particulate from gas streams (<http://www.epa.gov/apti/bces/module3/collect/collect.htm>).

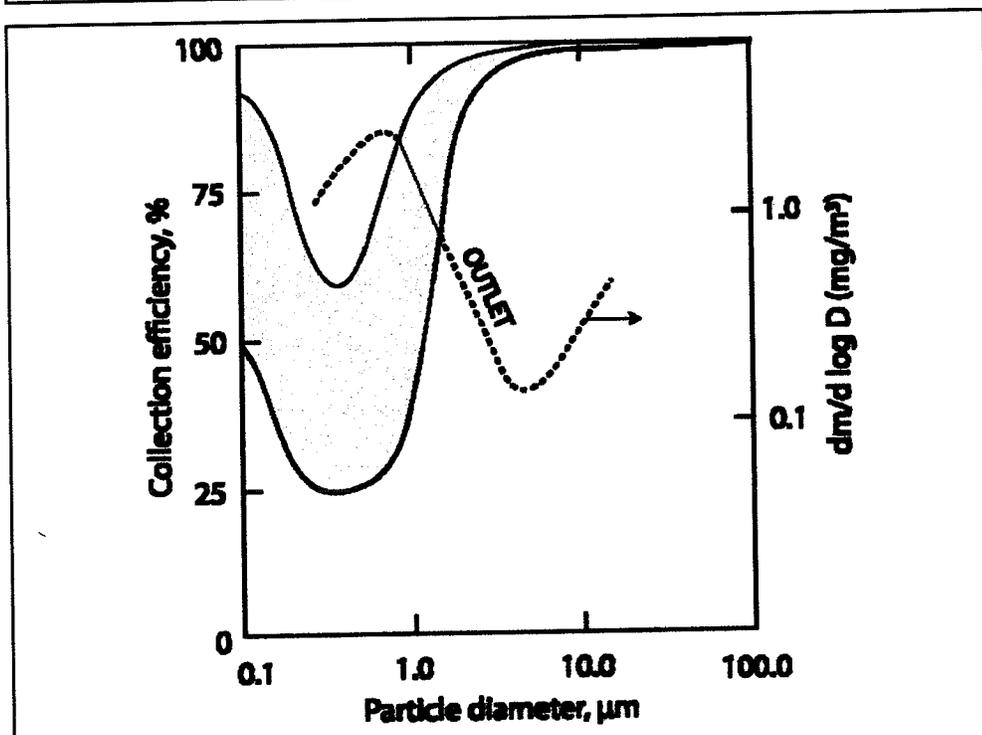


Figure 9. Particulate control efficiency for difficult to control particulate combined with the mass distribution of particulate collected downstream of the scrubber at MRYS (Markowski and others, 1983 and (<http://www.epa.gov/apti/bces/module3/collect/collect.htm>).

Aerosol Capture Efficiency in Scrubbers

As indicated by EPA (Woodward, 1998), scrubbers do not effectively remove particulate less than 1 μm in diameter. There is significant evidence that sodium-rich aerosols penetrate ESPs as well as scrubbers at full-scale power plants when firing high-alkali-containing fuels. An example is a biomass fired system using a tower type scrubber where the removal efficiency of the smaller size fraction of ash is low, as shown in Figure 10 (Ohlström and others, 2006).

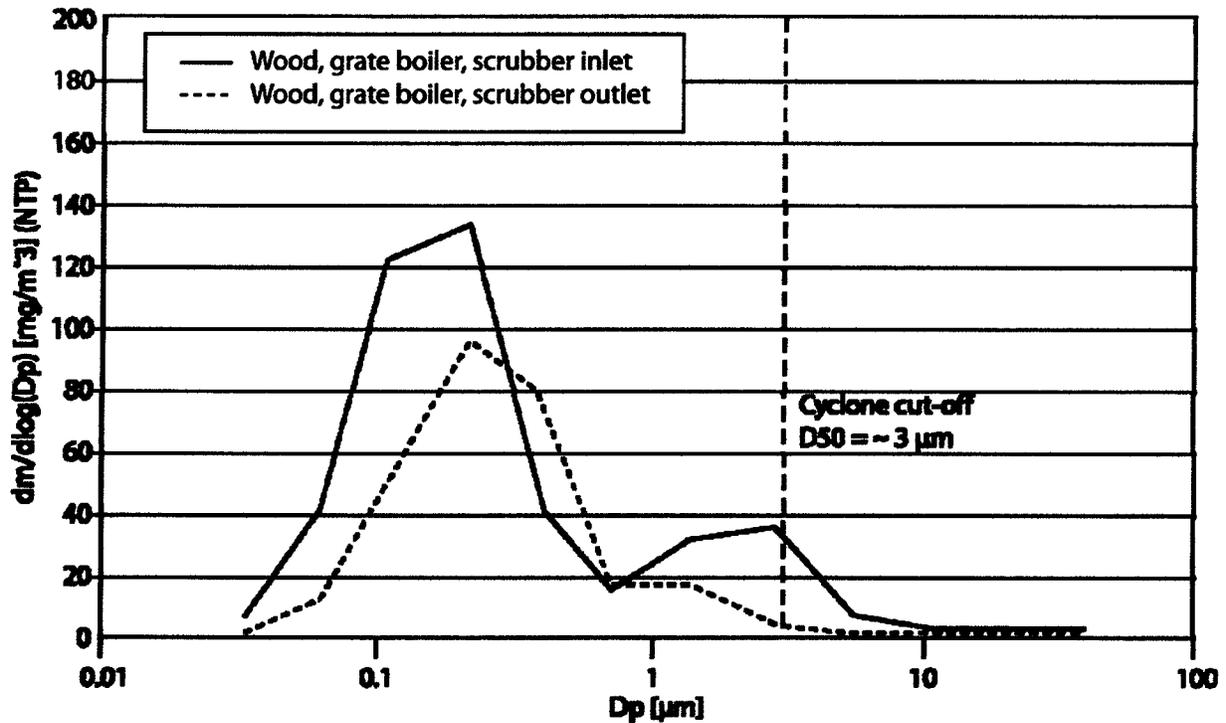
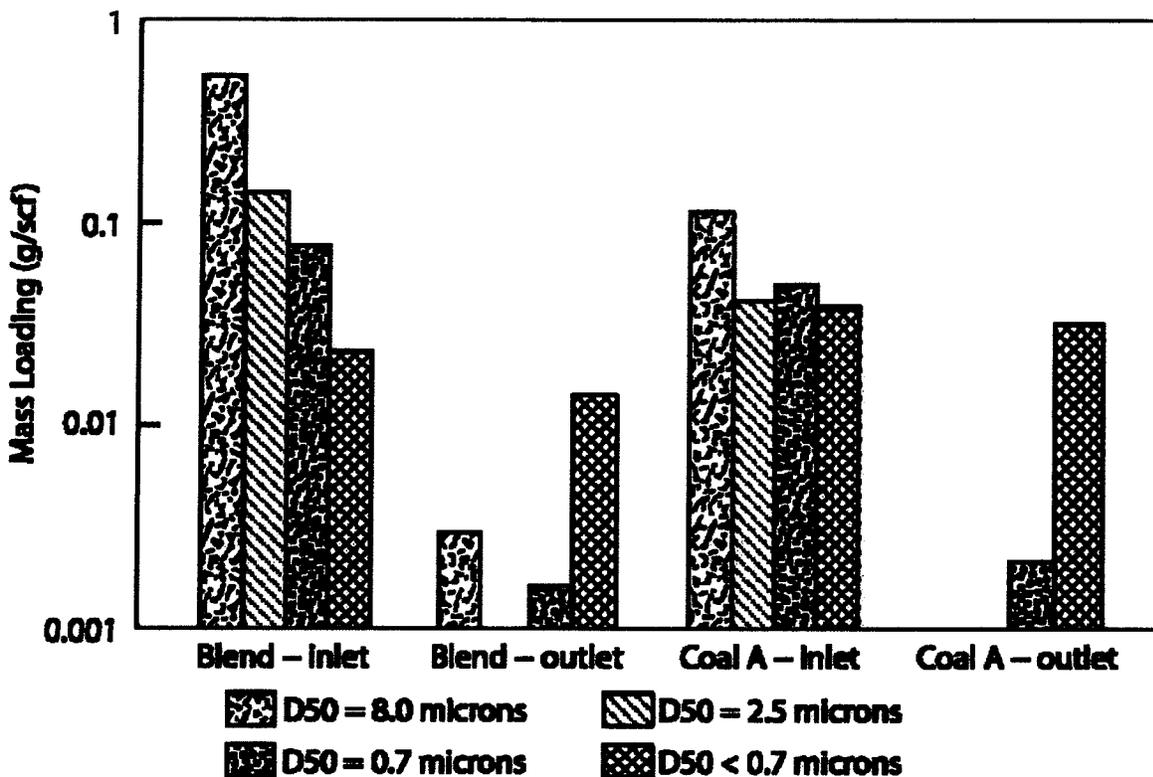


Figure 10. Removal of fine aerosols using a scrubber on a wood fired combustor (Ohlström and others, 2006).

Minnesota Power's Boswell Energy Station found that when it fired high-sodium, lower-ash northern Powder River Basin subbituminous coal (7% Na_2O in the ash), it experienced increases in opacity. Hurley and Katrinak (1992) conducted a field-testing project on Unit No. 4, a pulverized coal-fired boiler equipped with a venturi wet scrubber, to better understand the reasons for the opacity problems. During the field testing, sampling of the coals, flue gases, and scrubber materials was conducted. The particulate in flue gases downstream of the scrubber was aerodynamically classified using multicyclone followed by an impactor and a Nucleopore filter.

The sized fractions were weighed and analyzed to determine the abundance and composition of the submicron-sized fractions. The mass loadings in the various size bins are plotted in Figure 11, showing that the scrubber is quite effective in removing the larger particles. However, the scrubber is not very effective in removing the aerosols less than 1 micrometer in diameter for both the blended coal and the high sodium coal (Coal A).



Overall mass size distributions for entrained ash samples.

Figure 11. Mass loadings and size for particulate collected upstream and downstream of the wet venturi scrubber at Clay Boswell plant (Hurley and Katrinak, 1992)

The results of the study indicated that the particulate collected downstream of the scrubber was coal-related and caused by the high sodium content of the coals. Vapor-phase sodium condenses in the boiler's convective pass to form fine sodium-rich aerosols or other Na species that later react with ash particles. Pure Na_2SO_4 particles are too small to be removed by such scrubbing. Figure 12 shows the spikes of the ash material collected on Stage 10 of the impactor. This impactor accumulation represents particles of less than 0.7 to 2.5 micrometer size fraction of the

submicron aerosol. The spikes are made up of submicron particulate matter, and the chemical analyses of the spikes and ash particles collected on the Nucleopore filters downstream of the impactor plates are shown in Table 4. Both samples are dominated by sodium and sulfur that are likely in the form of sodium sulfate. These sulfate materials exhibit highly cohesive tendencies.

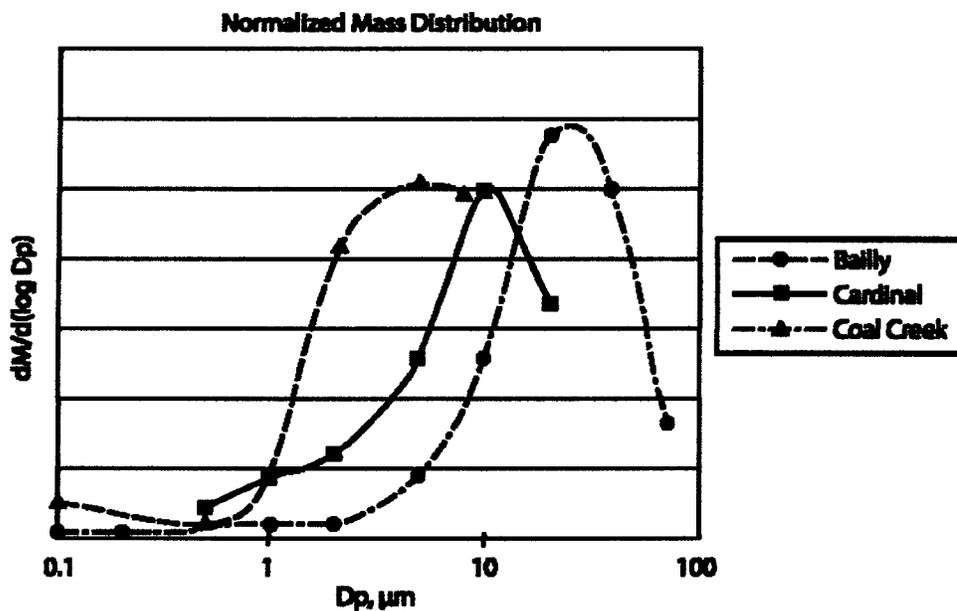


Figure 12. Scanning electron microscope images of spikes formed on impactor plates when high-sodium subbituminous coal is combusted (the picture on the right is a close-up of the spike) (Hurley and Katrinak, 1992).

Table 4. Chemical Composition of the Spike Shown in Figure 12 and the Filter (weight percent expressed as equivalent oxide).

Oxide	100% Coal A	
	Spike	Filter
Na ₂ O	35.1	17.3
MgO	1.4	7.8
Al ₂ O ₃	2.0	9.8
SiO ₂	9.1	10.6
P ₂ O ₅	0.4	0.2
SO ₃	39.7	28.0
K ₂ O	2.6	1.5
CaO	6.2	15.7
TiO ₂	0.2	1.8
Cr ₂ O ₃	1.4	0.1
Fe ₂ O ₃	0.9	2.9
BaO	0.5	2.6

In addition to the aforementioned testing results, penetration of submicron particles through ESP and scrubbers has been reported by numerous researchers (Markowski and others, 1983, and Lighty and others, 2000). Figure 13 shows the penetration of particulate from ND lignite to be the highest of the combustion systems tested as part of the DOE field test program.



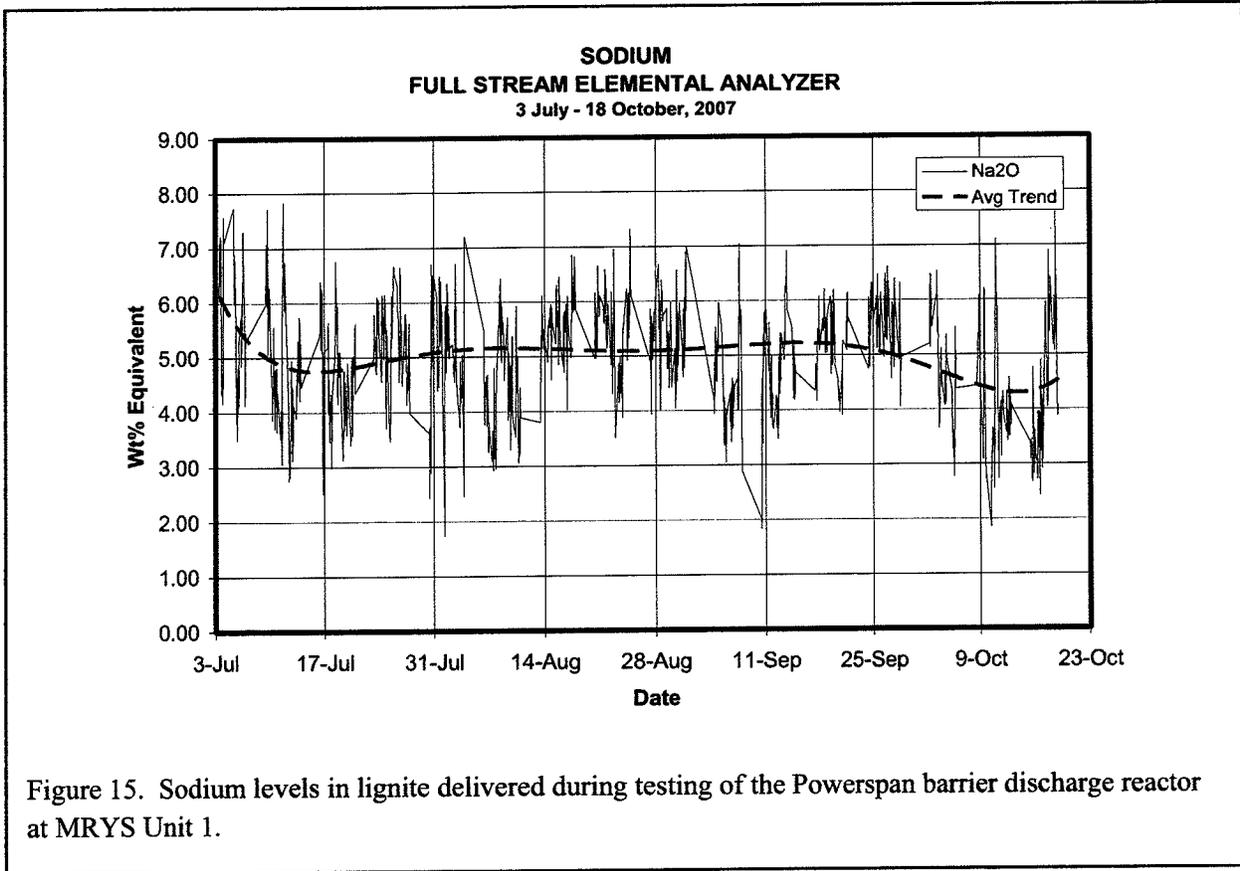
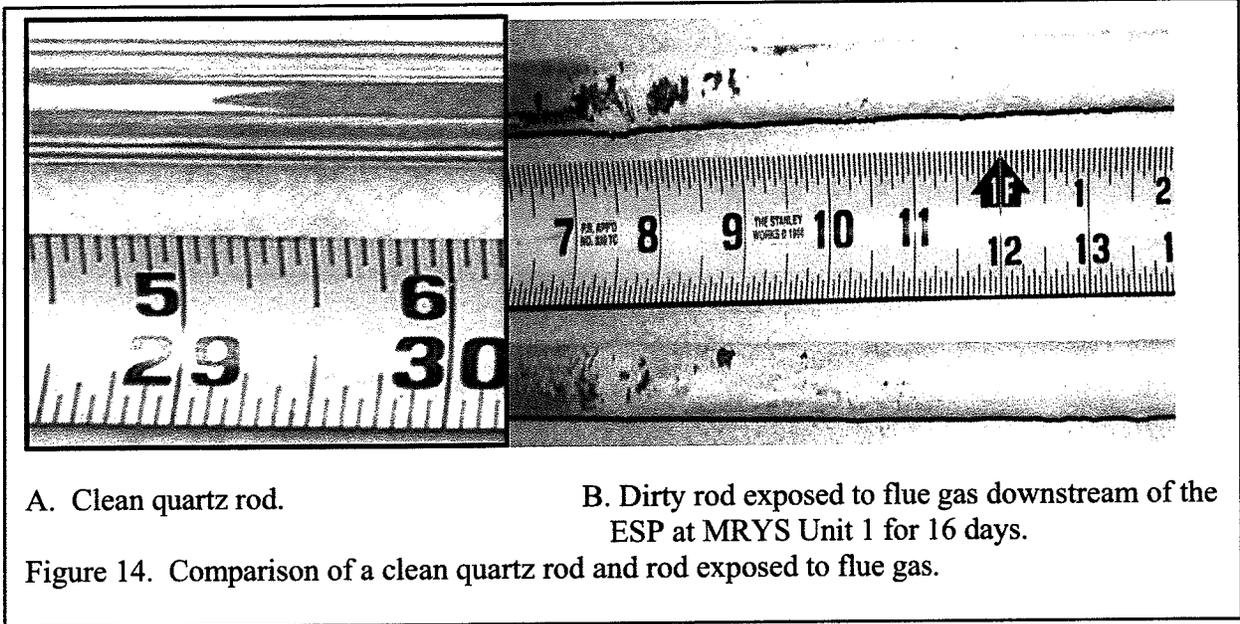
Plant	Description	Stack Emissions
Bailly	345 MW, Cyclone Burner Dry scrubber, ESP Illinois high-sulfur bituminous	60 kg/hr
Cardinal	615 MW, well-mounted cell burner ESP, no sulfur removal Pittsburgh No. 8 bituminous	100 kg/hr
Coal Creek	550 MW, tangential-fired Wet scrubber, ESP North Dakota lignite	260 kg/hr

Figure 13. Normalized differential particle mass distributions measured in the stack for a sample of coal-fired power plants using different burner and gas-cleaning technologies (Lighty and others, 2000).

Powerspan Testing at MRYS

The Powerspan slipstream electrocatalytic oxidation (ECO) reactor system was designed by Powerspan and the EERC (Tolbert and Benson, 2008). The slipstream system was installed by the EERC at Minnkota Power Company's Milton R. Young Station Unit 1 downstream of the ESP where the flue gas temperature ranged from 300°F to 350°F. The dielectric barrier discharge (DBD) reactor has quartz electrode rods inside where electric current is passed in order to generate the plasma used to oxidize nitrogen oxide (NO) to nitrogen dioxide (NO₂). The temperature of the quartz electrodes was approximately 100°F higher than the gas temperature. The system at MRYS was commissioned on July 3, 2007, and it operated for 107 days. Operational performance of the system was monitored and data were archived for post processing. A pair of electrodes was extracted and replaced on a bi-weekly basis. Each pair of electrodes was shipped to Powerspan for testing in their laboratory reactor for NO conversion testing. Tested electrodes were then shipped to the EERC for scanning electron microscopy imaging and x-ray microanalysis. Measurement of NO_x conversion in the field by the slipstream system was not possible due to the nitric acid production of the DBD reactor. Aerosols passing through the ESP at MRY Unit 1 resulted in significant accumulation on Powerspan's slipstream ECO barrier discharge reactor rods resulting in significant degradation in performance.

The operational observations, performance results, and lab testing showed that the system was adversely affected by ash fouling. NO_x conversion by ash covered electrodes was significantly reduced. Figure 14 visually compares a clean unexposed quartz rod to one exposed to flue gas and aerosols downstream of the ESP at MRY Unit 1. The abundance of sodium in lignite coal fired during the Powerspan testing at MRYS is shown in Figure 15. The results show sodium levels measured by the full stream elemental analyzer (FSEA) ranged from 3.5 to 6 % Na₂O in ash. Figure 16 shows the degradation in NO conversion measured during subsequent lab testing at EERC using the exposed quartz rods removed from the slipstream test ECO DBD reactor at MRYS as a result of being coated with aerosols. The NO conversion was severely impacted.



SAMPLING SCHEDULE					
SAMPLING DATE	LOCATION	REMOVE ROD #	DAYS IN REACTOR	REPLACE WITH ROD	DAYS IN REACTOR
3-Jul	START TESTING				
19-Jul	F K	6 11	16	15 16	91
1-Aug	M B	13 2	29	17 18	78
16-Aug	H D	8 4	44	19 20	63
30-Aug	C J	3 10	58	B1 B2	49
13-Sep	I G	9 7	86	B3 B4	35
27-Sep	E L	5 12	100	B5 B6	21
11-Oct	NO SAMPLES EXTRACTED DUE TO THE PROXIMITY TO THE FINAL SAMPLING.				
18-Oct	A N	1 14	107	All of the electrodes listed above will be removed for lab testing and analysis.	

Lignite Pilot Electrode Performance

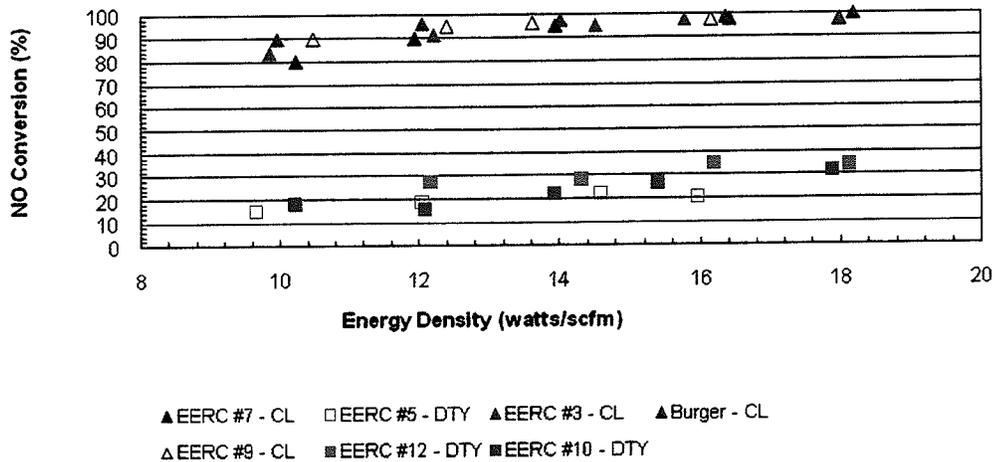
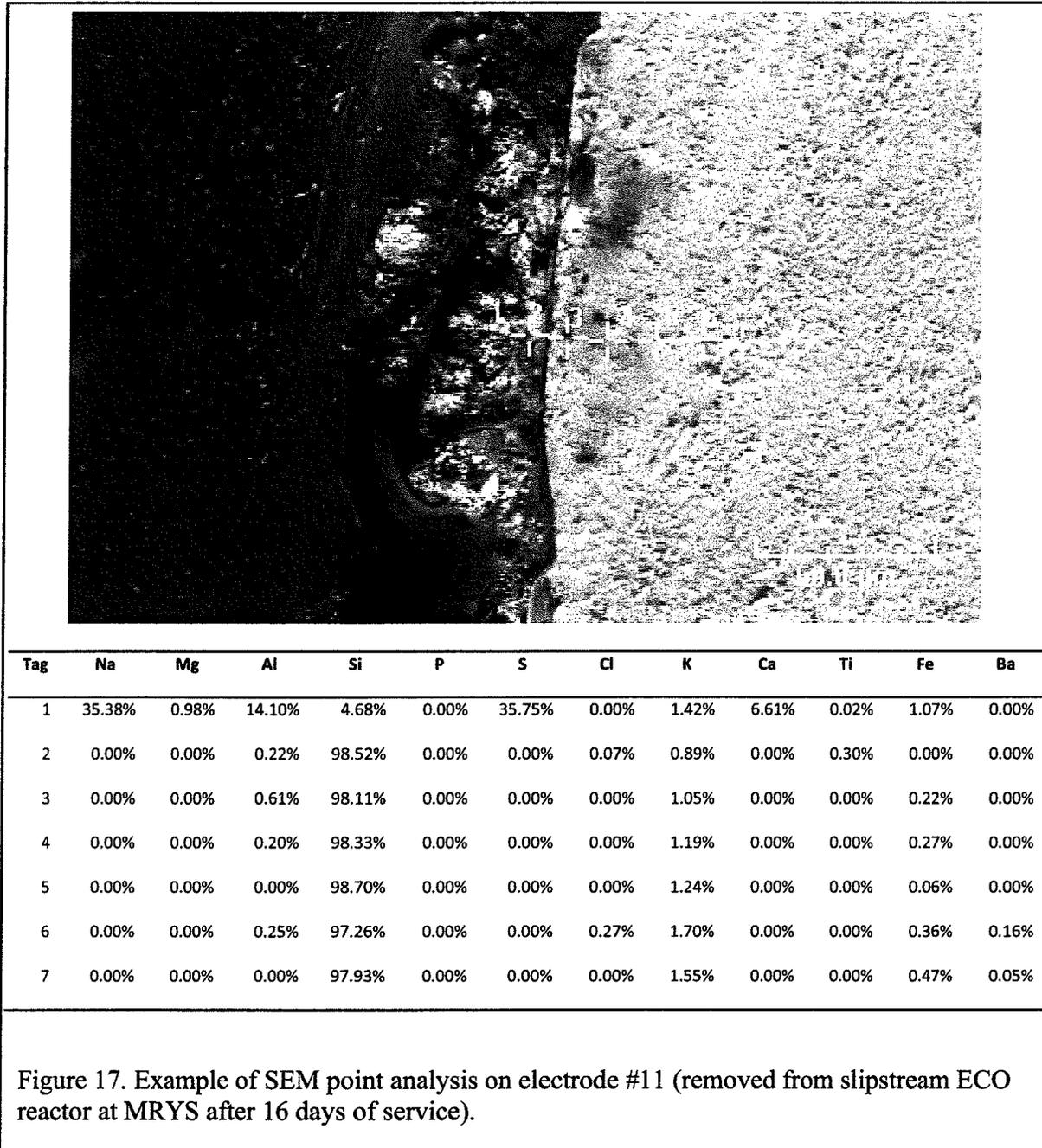


Figure 16. NO conversion for clean (CL) and dirty (DTY) for quartz tube exposed the flue gas during the MRYS testing. Burger is a slipstream pilot ECO system in Ohio used for reference.

Examination of the quartz rods removed from the slipstream ECO DBD reactor at MRYS (cross-sectioned to expose coating thickness) by EERC using scanning electron microscope equipped with an x-ray analyzer showed significant elemental sodium, sulfur, and calcium in the ash coating the tubes after only 16 days of testing. The data is reported on Figure 17. The thickness of the layer was approximately 25 μm . A sonic horn was used for in-service cleaning of the rod-tube deposits. Images of the reactor and coatings on the electrodes are shown in Figure 18.



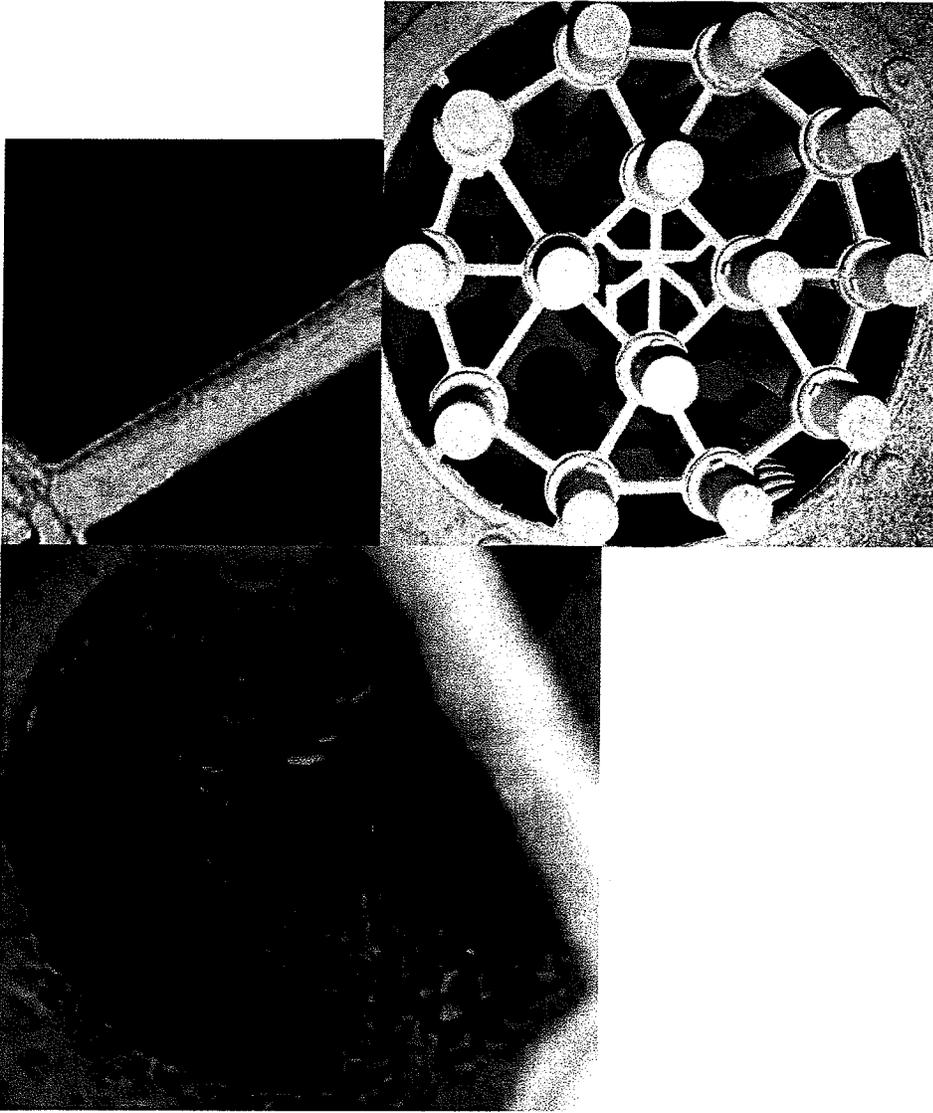


Figure 18. Images of top of slipstream ECO DBD reactor at MRYS showing ash accumulations on electrodes and reactor surfaces.

Conclusions gained by this work are:

- 1.) Sodium rich aerosols and small ash particles that had penetrated the ESP accumulate and become bonded on the surface of the silica electrodes despite using a sonic horn as recommended by Powerspan.
- 2.) Ash accumulations adversely affected the NO_x conversion.
- 3.) The adverse impact occurs within a two week time period.

MRY Sulfate Aerosol Sampling

The penetration of aerosols through ESP and wet scrubbers is well known and has been studied since the mid 1970s (McCain and others, 1975; Ensor and others, 1975). As a result of these challenges, the quantity of total aerosols and sulfate aerosols was measured at MRYS by Markowski and others, 1983. Markowski and others (1983) collected EPA method 17 particulate samples and size segregated the particles using an impactor that aerodynamically separates particles and allows for the characterization of each fraction. The results of the EPA method 17 samples conducted over a four day period. The mass concentrations of aerosols as determined by EPA method 17 sampling are illustrated in Figure 19 for the inlet and out of the scrubber. At the inlet aerosol mass concentrations ranging from a high of over 10,000 $\mu\text{g}/\text{m}^3$ to a low of 4000 $\mu\text{g}/\text{m}^3$. Significant levels were also found at the scrubber outlet ranging from 8800 to 2500 $\mu\text{g}/\text{m}^3$. The removal efficiency varied from -25 to 66%. Markowski and other (1983) offered no explanation of the differences in the levels of aerosols measured in the flue gas and removal efficiency. They did not consider that the ash content of the coal varied significantly during the testing. Results of testing at MRYS have shown significant differences in the quantity vaporized for coals that have different ash contents (see Figure 3). The variations in ash content shown in Figure 19 reflect changing coal characteristics that resulted in differences in aerosol mass concentration.

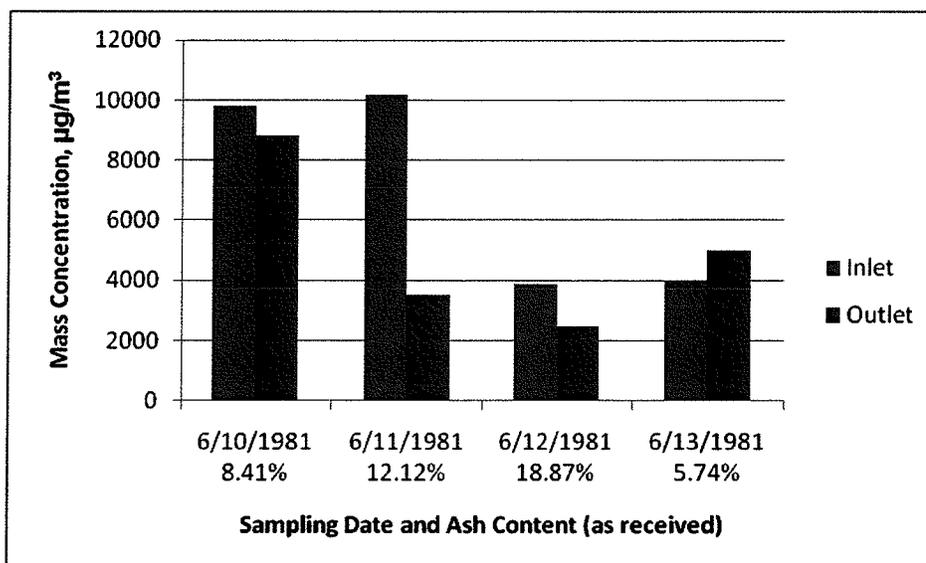


Figure 19. Mass Concentration of Aerosol Collected at MRYS Unit 2 at the Scrubber Inlet and Outlet (Markowski and others, 1983).

The results of the measurements of aerosol capture are illustrated in Figure 20. The results show that aerosols less than one micrometer in diameter are not effectively captured in the wet FGD at the MRY facility. The graph also indicates the penetration of the particles through the FGD as a function of particle size. The penetration is the outlet size distribution divided by the inlet size distribution. (Penetration = 1- efficiency). Markowski and others (1983) showed that the “metallic” sulfate aerosols (sodium sulfate) penetrated the FGD much more effectively than the larger particulate materials.

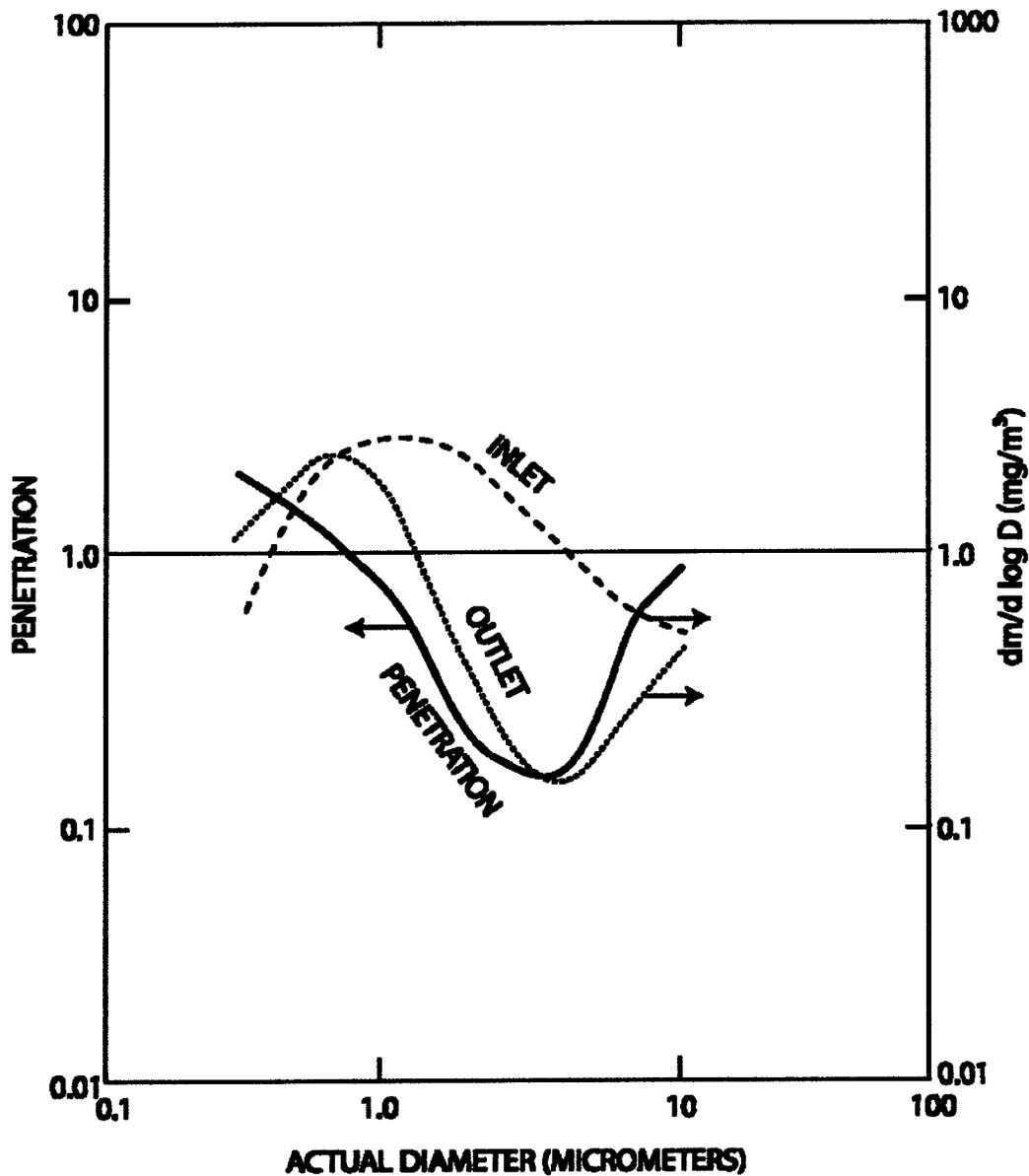


Figure 20. Penetration through the MRYS Unit 2 wet scrubber (Markowski and others, 1983).

The mass of each of the impactor size fractions for the aerosols collected at the inlet and the outlet of the wet FGD upstream and downstream of the MRYS Unit 2 scrubber are illustrated in Figure 21 and 22 with the results tabulated in Table 5. The total mass distributions are summarized in Figure 21 and the sulfate mass distribution is illustrated in Figure 22. Based on the impactor data the total mass of particulate that penetrates the scrubber is $5990 \mu\text{g}/\text{m}^3$ (Markowski and others, 1983). These ash materials consist of a combination of sulfates and

oxides of sodium, calcium, and sulfur. Much of the aerosol is present in the >14 μm size fraction. There are also significant mass in the less than 1 μm size fraction that has the potential to penetrate the pores of the catalyst. In addition, there is a significant mass in the <0.26 μm fraction. This fraction represents the ultrafine component that has been implicated as the most significant contributor to catalyst poisoning (Kling and others, 2007).

Table 5. Size segregated total and sulfate particulate collected upstream and downstream of the MRYS FGD (Markowski and others (1983)).

Size, μm	Inlet Total, $\mu\text{g}/\text{m}^3$	Outlet Total, $\mu\text{g}/\text{m}^3$	Inlet Sulfate, $\mu\text{g}/\text{m}^3$	Outlet Sulfate, $\mu\text{g}/\text{m}^3$
<0.26	1910	769	436	602
0.26-0.52	401	640	164	274
0.52-1.1	883	1410	293	459
1.1-2.5	1020	265	291	69.2
2.5-6.7	337	154	173	94
6.7-14	300	367	100	103
>14	700	2390	439	46.2
Total	5550	5990	1896	1650
>1.1	2357	3176	1003	312.4
<1.1	3194	2819	893	1335
Percent				
>1.1	42.5 %	53.0 %	52.9 %	18.9 %
<1.1	57.5 %	47.1 %	47.1 %	80.9 %

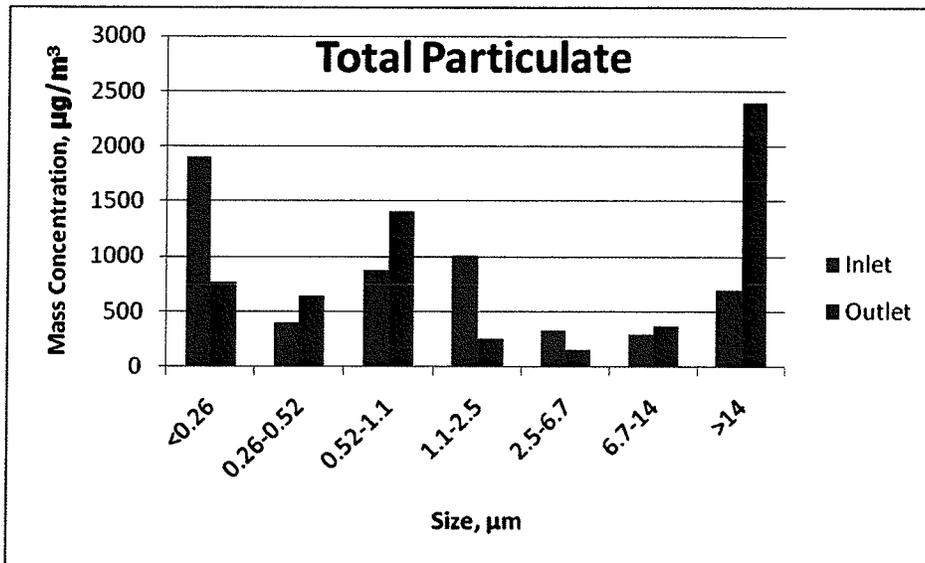


Figure 21. Total particulate removal across scrubber at MRYS.

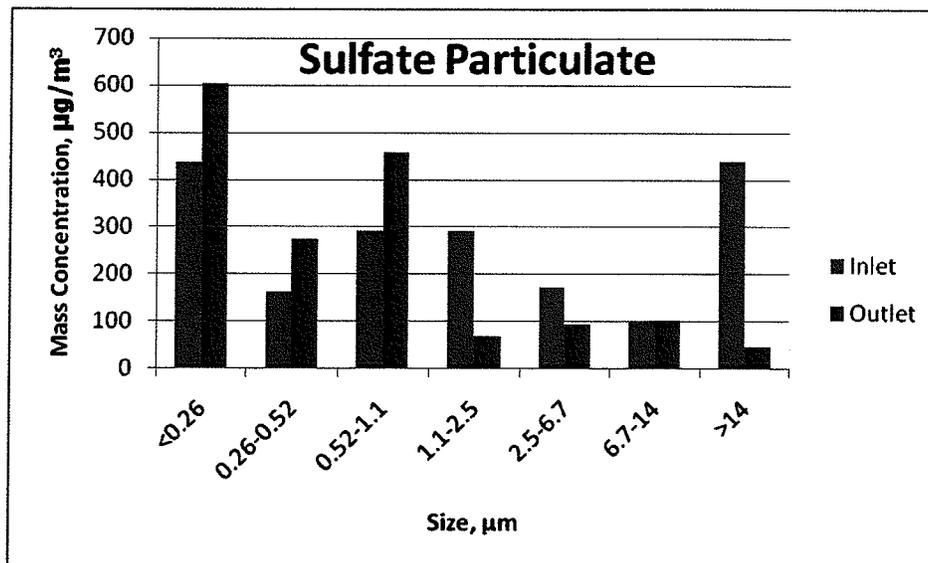


Figure 22. Sulfate particulate removal across scrubber at MRYS.

6. Determination of Sodium Loading Adversely Affecting SCR Catalyst Performance

Alkali metals such as potassium and sodium are known poisons and blinding agents for SCR catalysts used for NO_x emissions control. As previously discussed (Burns & McDonnell and others, November 2008) and repeated above, there will be submicron sodium, likely in sulfate

form, emitted from the dry ESPs at MRYS that will contaminate SCR catalyst located in a low-dust or tail-end configuration. The first fundamental issue is “how to estimate the amount (mass rate) of sodium and in what size range could be emitted from the boilers at MRYS, for the purposes of a BACT analysis”. Because BACT analyses on existing sources are not common, we also presume them to be “studies on paper using available information”. We do not consider BACT analyses as research projects requiring design of experiments, site-specific testing, and development engineering for the control technique being considered. Thus, this first issue is a significant challenge.

The second fundamental issue is “for the purposes of a BACT analysis, what rate of catalyst deactivation is likely to occur as a result of exposure to the expected particle or aerosol size range and concentration of sodium emitted from a boiler over a given period of time?”

Only by assuming that these fundamental issues can be resolved with the degree of certainty required for purposes of a BACT analysis, can such a comparison then be performed that could lead to a basis of technical feasibility of low-dust and tail-end SCR technology for MRYS.

Because most coals fired in utility boilers do not have the high sodium content of North Dakota lignite, and because cyclone boilers fire at high temperatures which promotes the emission of submicron sodium aerosols, there is not much published technical information that is available to help answer these fundamental questions. We can gain some insight into what might happen to SCR catalyst exposed to flue gas containing significant amounts of alkali salts by looking at the impact of co-firing biomass such as straw or switchgrass with coal. This is increasingly important to utilities that have chosen to pursue such a fuel mix strategy who also employ SCR technology on their boilers. We have previously commented on the high-dust SCR catalyst experience at the Avedore plant (Burns & McDonnell and others, November 2008) and the high frequency of catalyst washing performed to counteract the apparent highly negative impacts of biomass cofiring.

7. Alkali Aerosol Loading and Catalyst Deactivation

There is evidence that alkali aerosol loading in the flue gas streams results in catalyst deactivation. The total and sulfate aerosol mass loading measurements were conducted by Markowski and others (1983) at the inlet and outlet of the wet FGD scrubber at MRYS Unit 2.

The key data obtained by Markowski and others (1983) is illustrated in Figure 23 as well as the size fractionated data in Figures 21 and 22 provide information on loadings. The data provided shows a range of mass concentrations up to 8800 $\mu\text{g}/\text{m}^3$ at the outlet of the scrubber based on EPA method 17. Based on results in mass size distribution of the aerosol, 47 to 80% of the aerosols that pass through the scrubber are less than 1.1 μm . Much of this material is in the ultrafine fraction. These materials have the potential to penetrate into the catalyst, causing plugging, and can react with active components in the catalyst. There are numerous publications supporting these mechanisms. Kling and others (2007) found that the rate of catalyst deactivation was related to the accumulation of sodium and potassium on the catalyst as shown in Figure 24 and 25. The work by Kling and others (2007) is consistent with the work conducted by Khodayari, 2001 illustrated in Figure 26 where he shows that the deactivation rate is more significant for PC-fired systems as compared to fluidized beds. The work based on Kling and others (2007) when applied to PC and cyclone-fired systems will likely underestimate the degree of catalyst deactivation because of the firing methods.

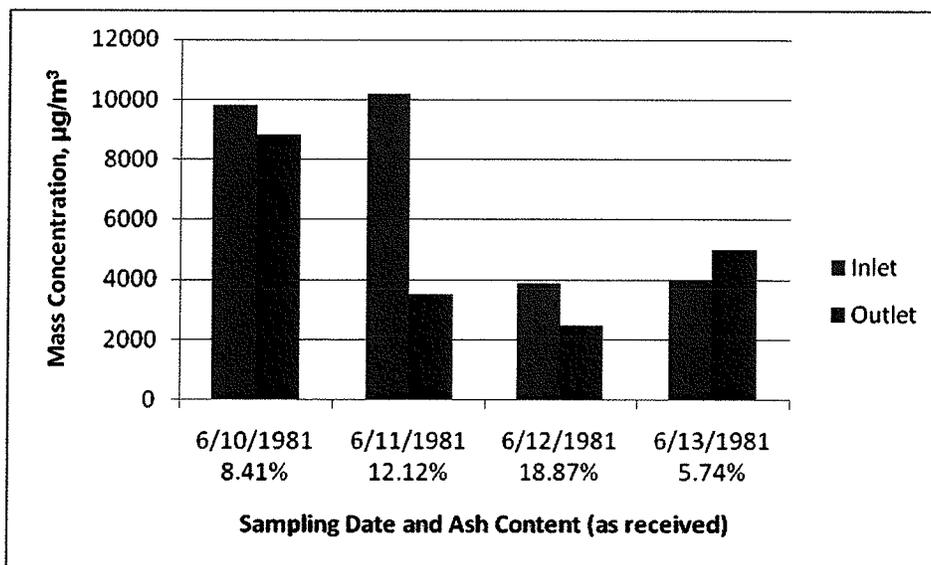


Figure 23. Mass Concentration of particulate collected at MRYS using EPA Method 17 (Markowski and others, 1983).

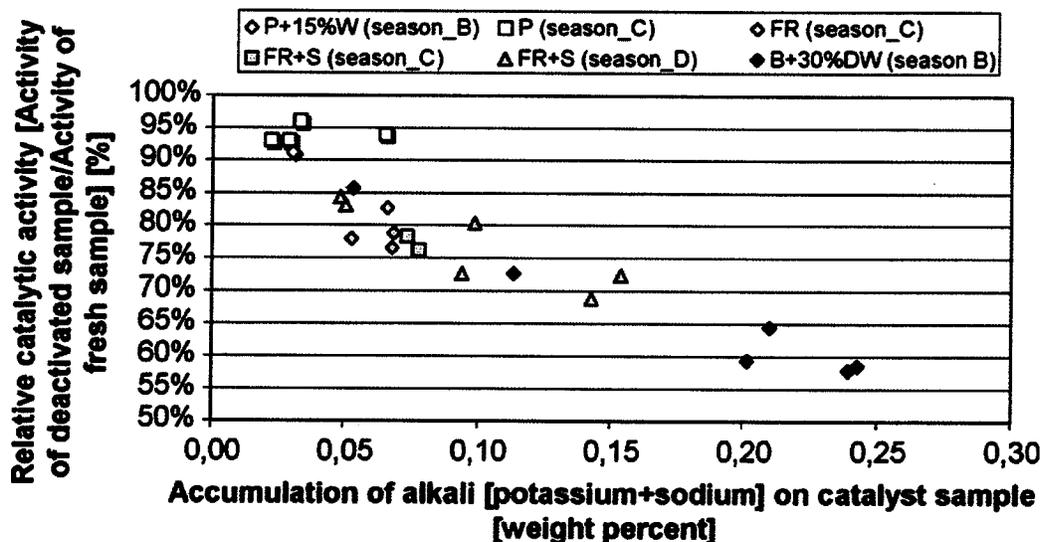


Figure 24. Catalyst deactivation compared to accumulation of potassium and sodium on the catalyst surface (Kling and others, 2007).

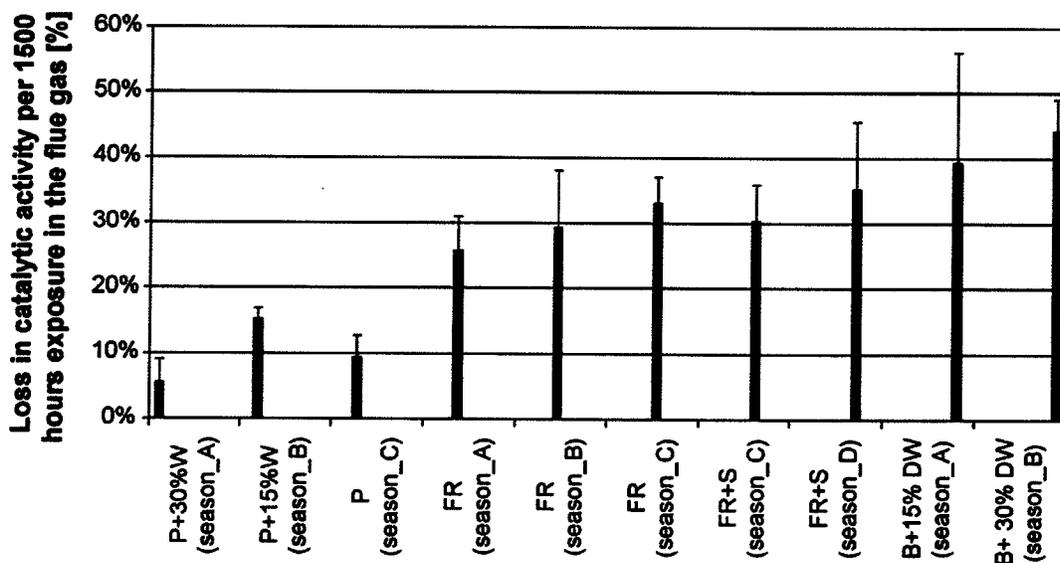


Figure 25. Loss in catalyst activity when exposed to flue gases containing vaporized Na and K when combusting biomass in a fluidized bed combustion system (Kling and others, 2007).

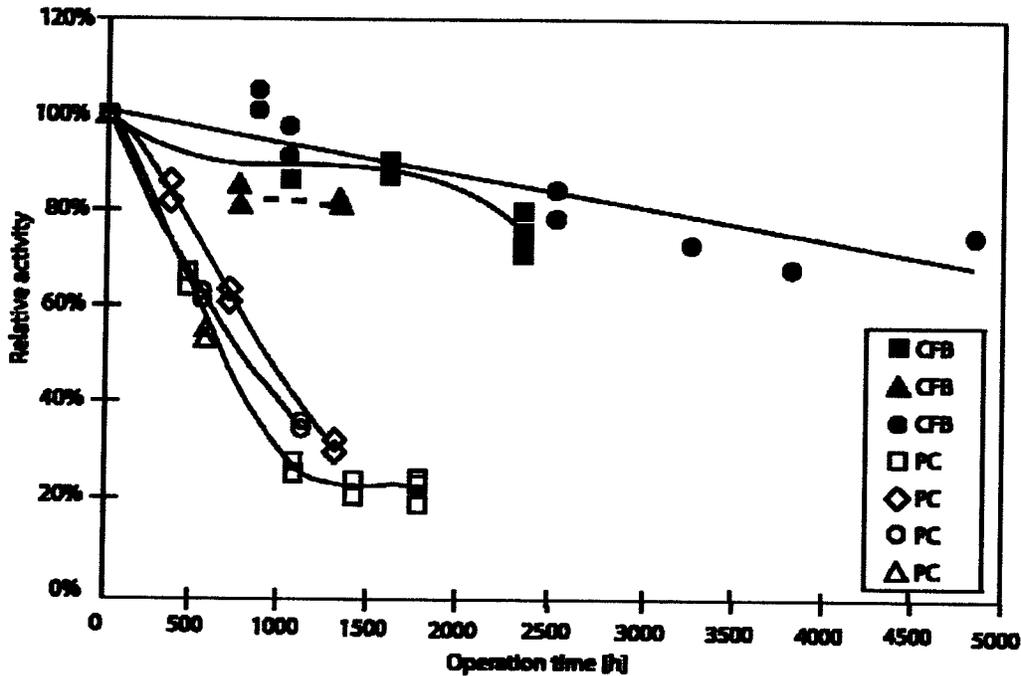


Figure 26. Comparison of poisoning of catalysts in a CFB boiler firing forest residues and in a PC firing pulverized wood (Khodayari, 2001).

There is a direct relationship to the concentration of sodium and potassium in the flue gas with accumulation on the catalyst and subsequent deactivation. The deactivation shown in Figures 24 and 25 directly relates the accumulation of sodium and potassium on the catalyst with deactivation. Deactivation rates of 40 to 55 percent (considering the error bars) was measured on catalyst that had accumulated 0.25 wt % sodium and potassium on the catalyst surface when exposed to flue gas containing $22,500 \mu\text{g}/\text{m}^3$ sodium and potassium for only 1500 hours. The flue gas downstream of the scrubber at the MRYS Unit 2 has been shown to contain aerosols at levels of $8800 \mu\text{g}/\text{m}^3$ with about 50% of the mass being less than $1.1 \mu\text{m}$. The ash that exits the ESP on Unit 1 is dominated by sodium and sulfur based on the results from the Powerspan testing. The quartz elements exposed to the flue gases for 16 days (384 hours) were completely covered with sodium and sulfur rich ash (see Figure 17). These elements were exposed to cleaning using a sonic horn. The sodium and sulfur rich ash produced a dense layer on the surface of the quartz rods approximately $25 \mu\text{m}$ thick in 384 hours. The MRYS results along with research efforts conducted in Europe show that masking and poisoning of SCR catalysts from flue gases containing alkali aerosols is a significant problem that has not been overcome by SCR catalyst vendors.

8. Experience of ESP/FGD Equipped Utility Plants Co-Firing Biomass and Coal with TESCR

In previous communications to NDDH, it was stated that no recent TESCR installations had been completed on utility boilers anywhere in the world. Burns & McDonnell subsequently learned about the Amager facility currently under construction in Copenhagen, Denmark that will involve a TESCR system on a multiple fuel-fired boiler that is expected to burn combinations of pulverized coal, wood pellets, straw, and fuel oil. A technical paper written by Haldor Topsoe described the design efforts for SCR_s on biomass (straw)-fired boilers (Crespi, and others, 2008) and indicated that the TESCR configuration was chosen specifically to address the concerns about catalyst poisoning due to the constituents of the straw (notably potassium). Follow-up communications were initiated by Burns & McDonnell with Haldor Topsoe, which supplied the catalyst for Amager's TESCR reactor; Alstom, which was the supplier of the SCR reactor system and the Flowpac wet FGD system (see attached project summary); and a plant engineer for the boiler's operator (Vattenfall A/S) (Burns & McDonnell personal communications, 2009). These personal communications provided the following information about this installation:

- a. The boiler is wall-fired and can be fired with oil (start-up), coal and wood- and straw-pellets. Coal and bio-pellets are pulverized in mills [prior to firing in the boiler], with full flexibility from 0 to 100 % straw. It is expected to fire 100% biomass most of the time. Maximum heat input to the boiler is 350 MW during coal and oil firing and 300 MW during wood/straw pellets firing.
- b. Danish regulations on emission include an emission fee (\$/ton of SO₂ or NO_x emitted), therefore the utility looks for the best compromise between low cost fuel and low emissions. The utility wants to be able to fire any mixture as specified above for the flexibility of cost and availability of both straw and coal. This is common for European customers who have to balance carbon dioxide (CO₂) emissions. When a new plant is built, the utility wants to make sure it can fire any fuel that may come on the market in the coming years without being limited by his boiler and cleaning equipment. Of the biofuels, straw is considered to be the most difficult as compared to woodchips, saw dust, paper, etc. The situation is the same in Sweden, Holland and some other countries.

- c. At the planning stages of the Amager project it was expected to co-fire biomass and coal in the boiler. Now, if bio-mass fuels are not available, 100% coal will be fired. When bio-mass is fired, NO_x emissions are expected to be low, so the utility is allowed to bypass the flue gas cleaning system. According to European regulations, the NO_x emission limit with bio-mass is 300 mg/Nm³ (dry 6% O₂). Both the FGD and the SCR systems will be bypassed, if NO_x in the flue gas emitted from boiler is below 300 mg/Nm³. No dampers are installed upstream of the TESCO. There is a global by-pass of both FGD and TESCO systems. The wet FGD and TESCO are mainly needed for any coal firing flue gas cleaning. When pure straw/ biomass is fired the whole wet FGD and SCR system can be bypassed, saving a lot of operating cost as both SO_x and NO_x will be within the limits from the authority. The client was not sure that they could get enough of straw available at an acceptable price, so the boiler had to have great fuel flexibility.

Based on this information, it appears that the Amager plant's TESCO system will typically be bypassed when the fuel firing conditions are most difficult for the SCR catalyst with regard to poisons. Consequently, Burns & McDonnell does not believe the Amager facility project under construction provides any indication that TESCO technology is technically feasible for application to MRYS.

9. Relevance of Recent TESCO investigations at We Energies' South Oak Creek Station

Recently, in response to a Consent Decree that requires the installation of SCR technology on Units 5, 6, 7 and 8 at its South Oak Creek Generating Station in Oak Creek, Wisconsin, We Energies (Wisconsin Electric) has investigated the use of TESCO technology. The investigation ultimately led to the determination that the TESCO approach would not be used. Based on information obtained by Burns & McDonnell from the engineering consultant and the technology vendor for that project (Burns & McDonnell personal communications, 2009), the decision not to use TESCO technology was based on economics. However, the fact that TESCO systems were considered to be feasible for specific application at the South Oak Creek units is not indicative that the same technology would be technically feasible for application at MRYS. This is due to

the substantial differences between the South Oak Creek boilers and the MRYS boilers, as summarized in the Table below:

Table 6. Comparison of Boilers for South Oak Creek and Milton R. Young Station

	South Oak Creek	Milton R. Young
Fuel Type	PRB Coal (low ash, very low sulfur)	ND Lignite
FGD Design Fuel Sulfur Content, SO₂ lb/mmBtu	1.15	3.95
Firing Type	PC wall-fired (Units 5 & 6) PC tangential (Units 7 & 8) (dry bottom)	Cyclone fired (Units 1 & 2) (slagging-type, wet bottom)
Design Boiler Outlet NO_x lb/mmBtu	0.15	0.51 (Unit 1 w/ASOFA) 0.49 (Unit 2 w/ASOFA)
Consent Decree NO_x Limit lb/mmBtu	0.10	TBD

The significant differences in the ash characteristics, especially with regard to the sodium content, between PRB coal and North Dakota lignite have been explained in previous submittals to NDDH (Burns & McDonnell and others, 2007 and 2008). The effect that cyclone firing has on the partitioning of sodium has been explained previously, and reiterated in this document. In addition, it can be seen from the tabulation above that the SO₂ content of the flue gas will be up to four times as high at MRYS as at South Oak Creek, either before or after the FGD system. This means that the potential for deposition of ammonium bisulfate on the SCR catalyst, due to the reaction between the ammonia reagent and the SO₃ that forms within the SCR reactor when catalytic SO₂ oxidation occurs, will be proportionally much greater for the application of TESCR technology to MRYS than it would have been at South Oak Creek. Finally, it should be noted that compliance with the Consent Decree for NO_x emissions in the case of South Oak Creek required only a moderate degree of emission reduction in the SCR systems, meaning that the design was not particularly challenging from a percentage reduction standpoint.

10. Relevance of Ongoing LDSCR Installation Project at We Energies' South Oak Creek Station

Following the elimination of TESCR systems from further consideration for the SCR retrofits required by the Consent Decree, We Energies is proceeding with the installation of LDSCRs at Units 5, 6, 7 and 8 at South Oak Creek. Again, as shown in Table 6, the significant differences between the fuel, firing type, sulfur content and NO_x reduction requirement support the contention that installation of LDSCR systems under construction at South Oak Creek does not constitute a demonstration that LDSCR technology is technically feasible for MRYS.

11. Relevance of Existing LDSCR Installation at PSEG Mercer Station

In response to a January 2002 Consent Decree that required the installation of SCR technology on Units 1 and 2 at its coal-fired electric generating station in Mercer County, New Jersey, PSEG Fossil (PSEG) has installed and operated LDSCR systems at this site since 2004 (Unit 2) and 2005 (Unit 1). However, the fact that LDSCR was considered to be feasible for specific application at the Mercer units is not indicative that the same technology would be technically feasible for application at MRYS. This is due to the substantial differences between the Mercer boilers and the MRYS boilers, as summarized in the Table below:

Table 7. Comparison of Boilers for Mercer and Milton R. Young Station

	Mercer	Milton R. Young
Fuel Type	Low-sulfur bituminous coal (Venezuelan and eastern U.S. blend)	ND Lignite
Firing Type	PC wall-fired, slagging-type (wet bottom)	Cyclone fired (slagging-type, wet bottom)
Design Boiler Outlet NO_x lb/mmBtu	1.40 (prior to controls) (see note below)	0.51 (Unit 1 w/ASOFA) 0.49 (Unit 2 w/ASOFA)
Consent Decree NO_x Limit lb/mmBtu	0.10	TBD

Mercer has demonstrated and employed various NO_x reduction techniques before LDSCR installation in 2004, primarily SNCR, with and without fuel-lean gas reburn, and in-duct SCR.

The significant differences in fuel type and firing type between these two plants would create very different flue gas characteristics of the flue gas entering the LDSCR, especially with regard to the sodium aerosol. The significant differences in the ash characteristics, especially with regard to the sodium content, between bituminous coal and North Dakota lignite have been explained in previous submittals to NDDH. The effect that cyclone firing has on the partitioning of sodium has also been explained previously, and reiterated in this document.

12. Additional Technical Feasibility Issues for TESCO at MRYS

As noted in previous submittals to NDDH (Burns & McDonnell and others, September and November, 2008), there are no existing or planned TESCRs on coal-fired utility power plants in the U.S. A review of the TESCR applications on German coal-fired power stations has indicated that these installations are configured basically as shown in the diagram on page 1 of this document. That is, flue gas from the outlet of the wet flue gas desulfurization (FGD) system absorber is reheated prior to entering the TESCR system, using a regenerative (Ljungstrom type) gas-to-gas heat exchanger (GGH) that supplies heat that was extracted from the flue gas upstream of the FGD. According to consultation with the designers of the LDSCR systems for South Oak Creek, the expected leakage through this type of heat exchanger will be at least 5.0 percent. When flue gas leaks across this “FGD GGH” from the inlet to the outlet flue gas stream, it effectively bypasses the FGD absorber, meaning that no SO₂ removal takes place from this slipstream of the total flue gas.

In the case of both MRYS Unit 1 (in the CD) and Unit 2 (in the proposed BART), NDDH has indicated that 95% SO₂ removal is required. This will preclude the use of this type of GGH, because, as leakage around the FGD system approaches five percent, it becomes *impossible* to achieve 95% overall SO₂ removal. This was not an issue for the German FGD systems, which were not required to achieve the same high level of SO₂ removal efficiency that is dictated by the MRYS CD and the proposed SO₂ BART.

This leakage could be avoided if the saturated flue gas from the FGD system absorber were sent directly to the “SCR GGH” upstream of the TESCO reactor as shown in the diagram on page 1. However, according to the engineering consultant who performed the evaluation of TESCO technology at South Oak Creek (as described in Section 9 above), “Saturated flue gas tends to be corrosive and there is virtually no experience with Ljungstrom GGH handling corrosive saturated gas. Saturated gas from the absorber tower carries gypsum slurry droplets, which tend to plug the cold end of the GGH with gypsum deposits that are extremely difficult to clean on-line.”

Another aspect of the TESCO approach that appears infeasible at MRYS is that the flue gas would enter the new fiberglass reinforced plastic (FRP) ductwork leading to the respective chimneys, and Unit 2’s FRP chimney liner, at a normal temperature above the 200°F design limit, due to the TESCO reactor’s outlet temperature being above 500 °F entering the treated-side of the SCR GGH.

Based on these considerations, the only way to apply TESCO technology to the units at MRYS while providing high SO₂ removal would be to employ a flue gas reheating technology which has not been proven in the application to a TESCO system at any full scale power plant installation. This indicates that TESCO technology is technically infeasible for application to the Units at MRYS.

13. Summary and Conclusions

- Because of the unique properties of Fort Union Lignites, they produce more vaporized ash (Na and other elements) than other coals including PRB and bituminous coal.
- Higher combustion temperatures associated with cyclone firing result in more ash vaporization and increased levels of submicron fine and ultrafine aerosol particles.
- Cyclones reduce the quantity of coarse flyash particles in the flue gas available to provide sites for sodium condensation and to dilute the bonding effects of the aerosols once deposited on a surface.
- The particle collection efficiencies for fine particles less than 1 µm are poor for both ESP and wet FGD, such as those utilized at MRYS.
- The number of flue gas particles per gram increases ten times for 1 µm versus 10 µm and another ten times for 0.1 µm versus 1 µm (diameter), so the fine and ultrafine aerosols are plentiful in number because of penetration through ESPs and scrubbers. These fine particles have high surface areas, are highly reactive, and readily bond together because of high surface energies.

- Particles in the 0.1 to 1.0 μm size fractions are largely composed of condensed vapor phase species such as sodium, potassium, and sulfur.
- Sodium-rich aerosol particles present in flue gas downstream of the ESP at MRYS Unit 1 significantly impacted the performance of the Powerspan slipstream ECO barrier reactor system in less than two weeks of exposure.
- Sodium- and sulfur- rich coatings on the surface of the Powerspan quartz rods were dense, continuous, and difficult to scrape off. These sodium and sulfur rich layers were produced in only 384 hours and were 25 μm thick.
- Emission rates downstream of ESP described in the reports provided by the NDDH range from 4,500 to 50,000 $\mu\text{g}/\text{Nm}^3$. The particulate emitted are dominated fine and ultra fine aerosols rich in sodium and potassium. NOTE: The level of 22,500 $\mu\text{g}/\text{Nm}^3$ of sodium- and potassium-rich fly ash derived from biomass firing resulted in catalyst deactivation of 30 to 40 % in 1500 hours (King and others, 2007).
- There are no TESCO installations in the U.S. on utility coal-fired boilers, and there are no examples of TESCO technology being applied worldwide on any coal-fired boilers having the same high percentage SO_2 removal requirements that are applicable at MRYS. The heat exchanger technology that has been employed on other TESCO systems for bituminous coal-fired boilers located in Germany, if applied at MRYS, will preclude compliance with the established SO_2 removal requirements.
- The expected outlet temperature from the TESCO and downstream gas-to-gas heat exchangers will be too high for the fiberglass flue gas ductwork exhausting the chimneys at MRYS.
- The existing LDSCR installations in the U.S. are on units firing coals and using coal firing technology that will not produce the same high level of catalyst poisons in the flue gas as would be the case at MRYS, where both units are cyclone furnaces firing high-sodium lignite.

Conclusions

In the end, arguments regarding the technical feasibility of tail-end and low-dust SCR technology at Milton R. Young Station are reduced to disputing the characterization of the gas stream characteristics and the impacts of those characteristics on boiler and emissions control operations. Those who suggest that these impacts can be resolved by the use of LDSCR and TESCO, and that such technology will work at MRYS without failure, cannot point to relevant data showing success at other coal-fired boiler SCRs which have such high levels of sodium in the fuel and the flue gas stream.

Considering the findings and conclusions presented above and previously, low-dust and tail-end SCR technology would not be available to apply to Units 1 and 2 at MRYS without extensive long-term pilot-scale testing and design development efforts. As BACT is not the selection of a pollution reduction technology that requires such research and development in order to determine

if it can be successfully deployed for full-time, full-scale operation, we believe that low-dust and tail-end SCR technology is not technically feasible at MRYS for Unit 1 and Unit 2 NOx emissions control (Arfmann and others, 2007).

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