

Minnkota Power

MPC COOPERATIVE, INC.

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August 16, 2007



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

Subject: SCR Pilot Testing

Dear Mr. O'Clair:

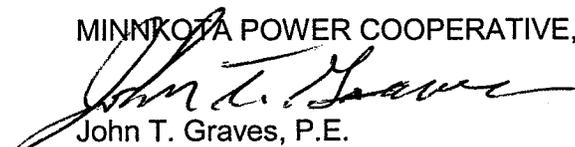
Enclosed, please find a report entitled "APPROPRIATENESS OF CONDUCTING PILOT TESTING OF SELECTIVE CATALYTIC REDUCTION (SCR) TECHNOLOGY AT MILTON R. YOUNG STATION UNITS 1 AND 2, FOR USE IN A NO_x BACT ANALYSIS". This report is submitted response to the Department's request that Minnkota consider a pilot test of SCR catalysts, at Milton R. Young Station, to gather additional data for use in Minnkota's previously submitted NO_x BACT analysis. This report addresses three aspects that must be considered when making a decision to pursue SCR catalyst pilot test. The aspects are: 1) the legal basis for the testing; 2) is there a reasonable expectation that the results would be different than the results of previous testing; 3) could the testing be accomplished in the required amount of time.

Based upon the information presented in the enclosed report, Minnkota has decided not to pursue SCR pilot testing at Milton R. Young Station, as elaborated in the document.

Should you have any questions concerning the above, or the enclosed document, please contact me by telephone at 701-795-4221 or by email at jgraves@minnkota.com.

Yours truly,

MINNKOTA POWER COOPERATIVE, INC.


John T. Graves, P.E.
Environmental Manager

C: David Sogard
Luther Kvernen
Craig Bleth
Kevin Thomas
Stu Libby
Tom Anseth
Young Station File

**APPROPRIATENESS OF CONDUCTING
PILOT TESTING OF SELECTIVE CATALYTIC
REDUCTION (SCR) TECHNOLOGY
AT MILTON R. YOUNG STATION UNITS 1 AND 2,
FOR USE IN A NO_x BACT ANALYSIS**

**Prepared For
MINNKOTA POWER COOPERATIVE, INC**

By

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August 14, 2007

BACKGROUND

The North Dakota Department of Health (NDDH) has requested that Minnkota Power Cooperative (Minnkota) consider performing a pilot test at the Milton R. Young Station (MRYS) to investigate the technical feasibility of Selective Catalytic Reduction (SCR) technology for control of emissions of nitrogen oxides (NO_x) from the North Dakota lignite-fired cyclone boilers at that power plant. The results of the pilot test would be used in the NO_x BACT analysis for MRYS. Technical feasibility of SCR application to utility boilers firing this fuel is a principal issue in the determination of best available control technology (BACT) for NO_x emission control at MRYS. The determination of BACT for NO_x emission control at MRYS is a requirement of the Consent Decree (CD) filed in the case *United States of America and State of North Dakota v. Minnkota Power Cooperative, Inc. and Square Butte Electric Cooperative*.

Minnkota has evaluated NDDH's request and has decided not to pursue SCR pilot testing at MRYS for three reasons as elaborated in this document, below. The reasons for not conducting further pilot testing prior to the BACT determination are:

1. Pilot testing is specifically not required by the BACT determination procedures established by the U.S. Environmental Protection Agency (EPA).
2. Previous research, including previous SCR pilot testing conducted at the Coyote Station, indicates that there is not sufficient reason to believe that the pilot testing suggested by NDDH will produce results any different from those obtained from the prior pilot test.
3. The compliance schedule for installation of NO_x BACT technology at MRYS as established by the CD cannot be met if pilot testing of SCR, followed by installation of SCR, is selected as the basis for BACT.

Each of these points is explained further in the text that follows.

REGULATORY BASIS FOR MINNKOTA'S DECISION NOT TO CONDUCT PILOT SCR TESTING

Minnkota's decision not to conduct pilot testing of SCR technology is supported on a regulatory basis for the following reasons:

1. EPA Guidance Specifically Describes When an Emission Control Technology is "Technically Feasible"

EPA has prepared a New Source Review Workshop Manual (Draft, October 1990) that explains, in detail, the evidence and analysis necessary to support a BACT determination. This process of defending a particular BACT recommendation is summarized in the Workshop Manual as follows:

The applicant's role is primarily to provide information on the various control options and, when it proposes a less stringent control option, provide a detailed

rationale and supporting documentation for eliminating the more stringent options. It is the responsibility of the permit agency to review the documentation and rationale presented and: (1) ensure that the applicant has addressed all of the most effective control options that could be applied; and (2) determine that the applicant has adequately demonstrated that energy, environmental, or economic impacts justify any proposal to eliminate the more effective control options. Where the permit agency does not accept the basis for the proposed elimination of a control option, the agency may inform the applicant of the need for more information regarding the control option. However, the BACT selection essentially should default to the highest level of control for which the applicant could not adequately justify its elimination based on energy, environmental and economic impacts. If the applicant is unable to provide to the permit agency's satisfaction an adequate demonstration for one or more control alternatives, the permit agency should proceed to establish BACT and prepare a draft permit based on the most effective control option for which an adequate justification for rejection was not provided. [Workshop Manual at B.53.]

The Workshop Manual requires an applicant to “make a good faith effort to compile appropriate information from available information sources, including any sources specified as necessary by the permit agency.” [*Id.* at B.11]. This analysis should at least identify technologies that may be potentially transferable to the particular source, though later those technologies may prove technically infeasible or economically cost-ineffective.

For each alternative emission control technique, the applicant should analyze whether the control technique is feasible. EPA defines a *technically feasible alternative as one that is available* (i.e., commercially available for the application in question) *and applicable* (i.e., whether the available controls may reasonably be deployed on the source in question). The Workshop Manual provides a detailed analysis of the availability and applicability of a control technology, which bears quoting at length:

In step 2, the technical feasibility of the control options identified in step 1 is evaluated. This step should be straightforward for control technologies that are demonstrated—if the control technology has been installed and operated successfully on the type of source under review, it is demonstrated and technically feasible. For control technologies that are not demonstrated in the sense indicated above, the analysis is somewhat more involved.

Two key concepts are important in determining whether an undemonstrated technology is feasible: “availability” and “applicability.” As explained in more detail below, a technology is considered “available” if it can be obtained by the applicant through commercial channels or is otherwise available within the common sense meaning of the term. An available technology is “applicable” if it can reasonably be installed and operated on the source type under consideration. A technology that is available and applicable is technically feasible.

Availability in this context is further explained using the following process commonly used for bringing a control technology concept to reality as a commercial product:

- Concept stage;
- Research and patenting;
- Bench scale or laboratory testing;
- Pilot scale testing;
- Licensing and commercial demonstration; and
- Commercial sales.

A control technology is considered available, within the context presented above, if it has reached the licensing and commercial sales stage of development. A source would not be required to experience extended time delays or resource penalties to allow research to be conducted on a new technique. Neither is it expected that an applicant would be required to experience extended trials to learn how to apply a technology on a totally new and dissimilar source type.

Consequently, technologies in the pilot scale testing stages of development would not be considered available for BACT review. An exception would be if the technology were proposed and permitted under the qualifications of an innovative control device consistent with the provision of 40 CFR 52.21(v) or, where appropriate, the applicable SIP.

Commercial availability by itself, however, is not necessarily sufficient basis for concluding a technology to be applicable and therefore technically feasible. Technical feasibility, as determined in Step 2, also means a control option may reasonably be deployed on or “applicable” to the source type under construction.

Technical judgment on the part of the applicant and the review authority is to be exercised in determining whether a control alternative is applicable to the source type under consideration. In general, a commercially available control option will be presumed applicable if it has been or is soon to be deployed (e.g., is specified in a permit) on the same or a similar source type. Absent a showing of this type, technical feasibility would be based on examination of the physical and chemical characteristics of the pollutant-bearing gas stream and comparison to the gas stream characteristics of the source types to which the technology had been applied previously. Deployment of the control technology on any existing source with similar gas stream characteristics is generally sufficient basis for concluding technical feasibility barring a demonstration to the contrary. [*Id.* at B.17–B.18] (emphasis added).

The *proper method for showing technical infeasibility* is identified by the Workshop Manual as follows:

[T]he applicant should make a factual demonstration of infeasibility based on commercial unavailability and/or unusual circumstances which exist with application of the control to the applicant's emission units. Generally, such a demonstration would involve an evaluation of the pollutant-bearing gas stream characteristics and the capabilities of the technology. Also a showing of unresolvable technical difficulty with applying the control would constitute a showing of technical infeasibility (e.g., size of the unit, location of the proposed site, and operating problems related to specific circumstances of the source). Where the resolution of technical difficulties is a matter of cost, the applicant should consider the technology as technically feasible. The economic feasibility of a control alternative is reviewed in the economic impacts portion of the BACT selection process.

A demonstration of technical infeasibility is based on a technical assessment considering physical, chemical and engineering principles and/or empirical data showing that the technology would not work on the emissions unit under review, or that unresolvable technical difficulties would preclude the successful deployment of the technique. Physical modifications needed to resolve technical obstacles do not in and of themselves provide a justification for eliminating the control technique on the basis of technical infeasibility. However, the cost of such modifications can be considered in estimating cost and economic impacts which, in turn, may form the basis for eliminating a control technology (see later discussion at V.D.2). [*Id.* at B.19–B.20.]

Each of the elements of demonstrating technical infeasibility, along with background and supporting information as necessary, must be decisively documented.

2. Following the Guidance from the Workshop Manual, Minnkota has Decisively Documented that SCR is Technically Infeasible at Milton R. Young Station

SCR has not been demonstrated on any North Dakota lignite-fired cyclone unit. In light of this lack of demonstration, NDDH has asked Minnkota to consider conducting pilot testing of SCR to determine the life expectancy of a particular SCR catalyst. However, the 1990 Workshop Manual concludes that pilot testing of an undemonstrated technology cannot be required as a part of a BACT analysis.

The Workshop Manual addresses technical feasibility in the context of both demonstrated technologies (not applicable to Minnkota here) and undemonstrated technologies (Minnkota's situation). As set forth in detail above, the key questions in determining whether the undemonstrated technology is feasible are whether the technology is "available" and "applicable." Most importantly, the Workshop Manual states:

"A source would not be required to experience extended time delays or resource penalties to allow research to be conducted on a new technique. Neither is it expected that an applicant would be required to experience extended trials to learn how to apply a technology on a totally new and dissimilar source type.

Consequently, technologies in the pilot scale testing stages of development would not be considered available for BACT review.” [Id. at B.18].

As Minnkota has demonstrated in its previous filings, EERC and Burns & McDonnell have demonstrated SCR cannot be reasonably installed and operated on the Milton R. Young Station. SCR is therefore unavailable and inapplicable, and NDDH may not require Minnkota to conduct extensive pilot testing as a part of a BACT analysis to experiment with the availability or applicability of SCR to North Dakota lignite-fired cyclone boilers.

In conclusion, Minnkota has demonstrated that SCR is not technically feasible, that SCR is not “available” under the EPA guidance, that SCR is not “applicable” under the EPA guidance, and that a pilot test is not allowed under the EPA guidance for BACT.

TECHNICAL BASIS FOR MINNKOTA’S DECISION NOT TO CONDUCT PILOT SCR TESTING

In order to determine if additional pilot testing of SCR catalysts on lignite fueled cyclone-fired boiler would produce similar or potentially different results from previous testing, the fouling and poisoning mechanisms must be examined. This is necessary in order to evaluate design changes that could be made to reduce or eliminate the fouling and poisoning of the SCR catalysts.

Fouling and poisoning of SCR catalysts are affected by the following:

- Lignite properties
- Combustion processes
- Partitioning of sodium and other elements during combustion
- SCR catalyst characteristics and properties
- Chemical and physical mechanisms of pore plugging

The primary concern for lignite coals from the Northern Great Plains of North America is blinding and poisoning of SCR catalysts because of the presence of alkali and alkaline elements in the coal and their fate upon combustion. Mussatti (2002) indicated in the “EPA Air Pollution Control Cost Manual – Sixth Edition” the following primary mechanisms for catalyst deactivation:

“Poisoning - Certain fuel constituents which are released during combustion act as catalyst poisons. Catalyst poisons include **calcium oxide and magnesium oxide**, potassium, **sodium**, arsenic, chlorine, fluorine, and lead. These constituents deactivate the catalyst by diffusing into active pore sites and occupying them irreversibly. Catalyst poisoning represents the main cause of catalyst deactivation.”

“Blinding/Plugging/Fouling - Ammonia-sulfur salts, fly ash, and other particulate matter in the flue gas cause blinding, plugging or fouling of the catalyst. The particulate matter deposits on the surface and in the active pore sites of the catalyst. This results in a decrease

of the number of sites available for NO_x reduction and an increase in flue gas pressure loss across the catalyst.”

Based on research, development, and demonstration testing to date these challenges have not been overcome. Significant fundamental research is required to further develop NO_x reduction technologies for lignite coals.

Lignite Properties

Lignite from the Center Mine in North Dakota is part of the Fort Union region. The Fort Union region represents the lignite bearing reserves in North America. The age of lignite in the Fort Union ranges from late Cretaceous through Eocene. The younger lignite coals have higher levels of oxygen as compared to higher ranked coals. Lignites can contain as high as 20% oxygen on a moisture and ash free basis. The most important oxygen containing group in lignite is the carboxylic acid group accounting for up to 65% of the oxygen (Schobert, 1995). The carboxylic acid groups act as bonding sites for various elements such as Ba, Ca, Mg, Na, and Sr and are enriched in lignite coals as compared to bituminous coals (Schobert, 1995). As coal rank increases the oxygen functional groups are lost due to the coalification process. The carboxylic acids act as ion exchange sites for sodium and other elements such as Mg, Ca, Sr, and Ba that are accumulated from ground water. The abundance of sodium and other elements that are associated with the carboxylic acid groups in the coal are determined using chemical fractionation (Benson and Holm, 1985). The chemical fractionation results for Center lignite indicates that 76% of the total sodium is ion-exchangeable indicating an organic association in the coal with the remaining in a water soluble form (Schobert, 1995). In addition to the organic and water associated impurities, lignites contain significant levels of mineral grains. The types of minerals present in lignite consist of pyrite, quartz, clay minerals, sulfates, carbonates, and others (Benson and others, 1993).

Lignite fired at the Milton R. Young (MRY) plant is mined from three seams at the Center mine of the Fort Union Region, the Kinneman Creek (KC), Hagel A (HA), and Hagel B (HB). The coal fired in the Units 1 and 2 represent some blending of the coal through handling and delivery. The variability selected coal quality components for the as-fired Center lignite is shown in Table 1. The average, maximum, and minimum as well as the percentiles were derived from analysis of the as-fired coal database. The database consists of 1316 samples of coal collected using sampling systems on Unit 2. The elements that are largely organically associated as described above are highlighted. These elements are largely organically associated and can contribute to the formation of reactive fine particulate during combustion and gas cooling.

Table 1. Center lignite 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 produced at 750 °C).

	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
Max	39.37	25.46*	2.55	7101	15.62	1.22	23.96	24.72	7.09	1.00	2.30	55.98	13.03	34.50
Min	33.56	4.97	0.47	5852	6.31	0.20	6.80	5.38	2.30	0.01	0.16	12.30	0.55	8.12
90th Perc.	38.10	12.51	1.29	6820	14.23	0.84	19.92	12.20	5.68	0.41	1.92	45.98	8.71	26.25
10th Perc.	35.95	7.06	0.72	6359	9.58	0.37	9.73	7.08	3.00	0.04	0.61	22.70	1.99	14.35
45th Perc.	37.17	9.33	0.90	6552	11.62	0.47	12.15	8.34	3.81	0.09	1.36	36.99	4.09	17.30
55th Perc.	37.37	9.75	0.94	6592	11.97	0.50	12.74	8.68	3.97	0.10	1.44	38.36	4.61	18.02

* High value may be an analysis or reporting error. Sample could not be reanalyzed to verify.

Figures 1 - 3 show the frequency distributions with the 10th, 50th, and 90th percentile values for sodium, base-to-acid ratio, and ash content in the as-fired database. In addition, the future Center lignite characteristics in ten-year averages for % sodium oxide in ash, base/acid ratio, and % ash are plotted on the frequency distribution diagrams in Figures 1-3. The future Center lignite characteristics are based on weighted averages of analysis conducted for drill cores. This information was used to calculate the weighted averages for 10-year spans. The frequency distribution of the sodium content of the ash is shown in Figure 1. The projections for the future have similar sodium levels to the upper mode of sodium contents. The sodium content of the future coals appears to be decreasing initially from the upper mode and then increasing from 2036–2064. The base-to-acid ratio shown in Figure 2 indicates coals typical of lower ash contents and high levels of sodium, calcium, potassium, and iron relative to silicon, aluminum, and titanium. This information indicates that the future coals will have a higher propensity on average to cause low-temperature fouling than coals fired over the past several years. Lower ash content and higher base-to-acid ratio coals produce more low temperature fouling due to sulfate formation. Figure 3 shows the projected ash values compared to the as-fired database. The data from 2006–2015 show similar data to the as-fired database with decreasing levels of ash in the latter years.

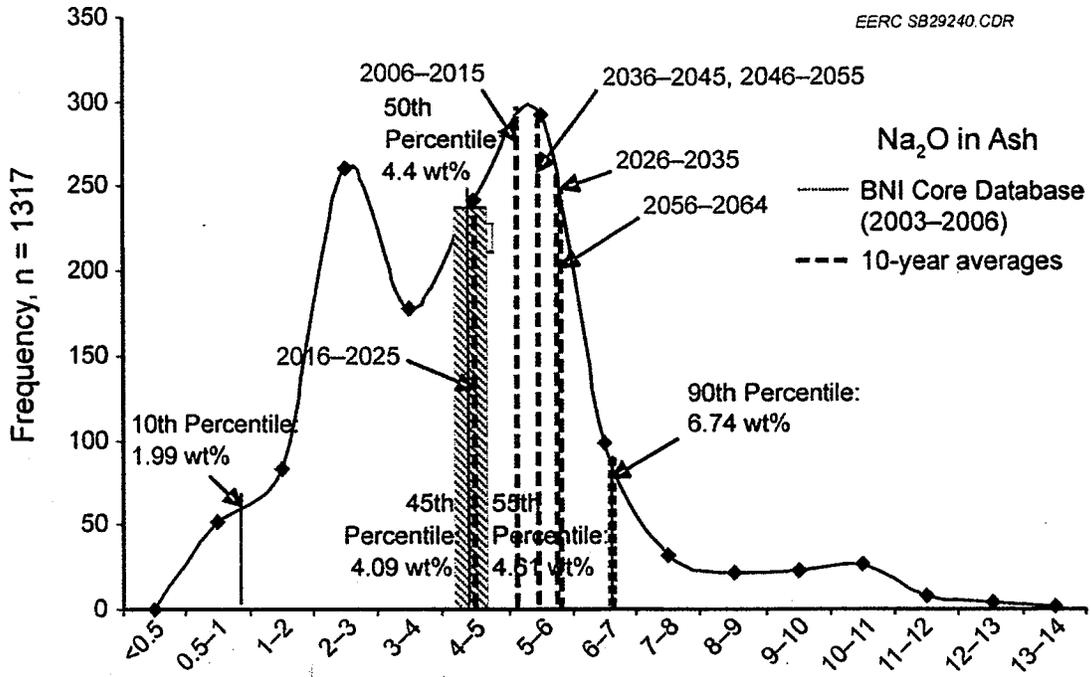


Figure 1. Sodium oxide in ash frequency distribution for as-fired database compared to 10-year averages and weighted Core Database values.

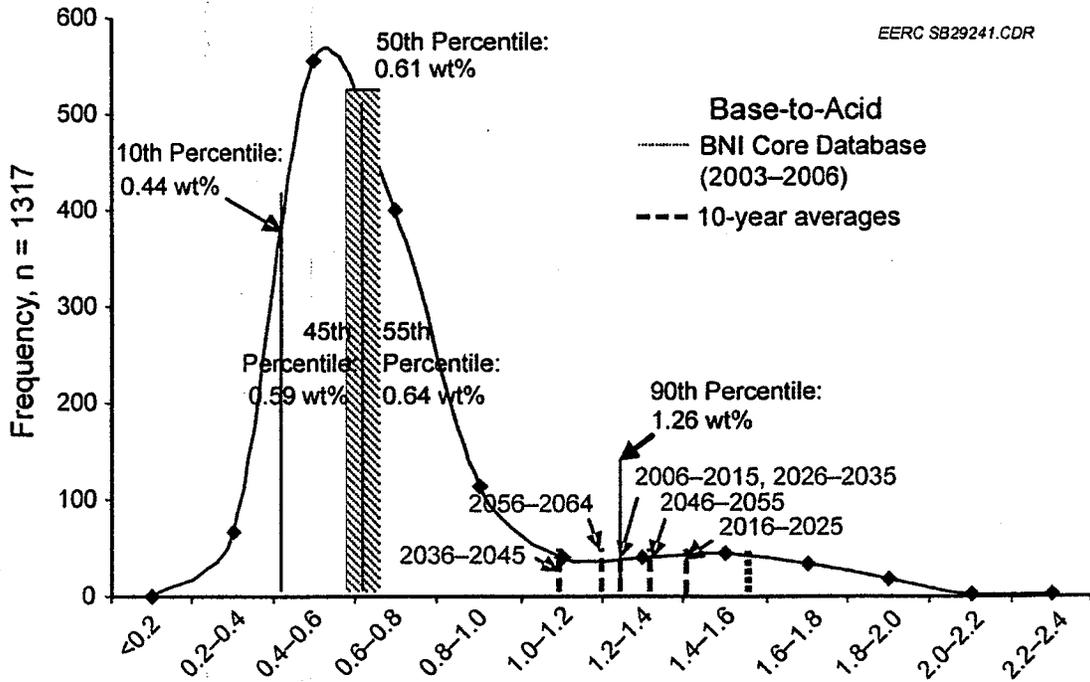


Figure 2. Base-to-acid ratio of ash frequency distribution for as-fired database compared to 10-year averages and weighted Core Database values.

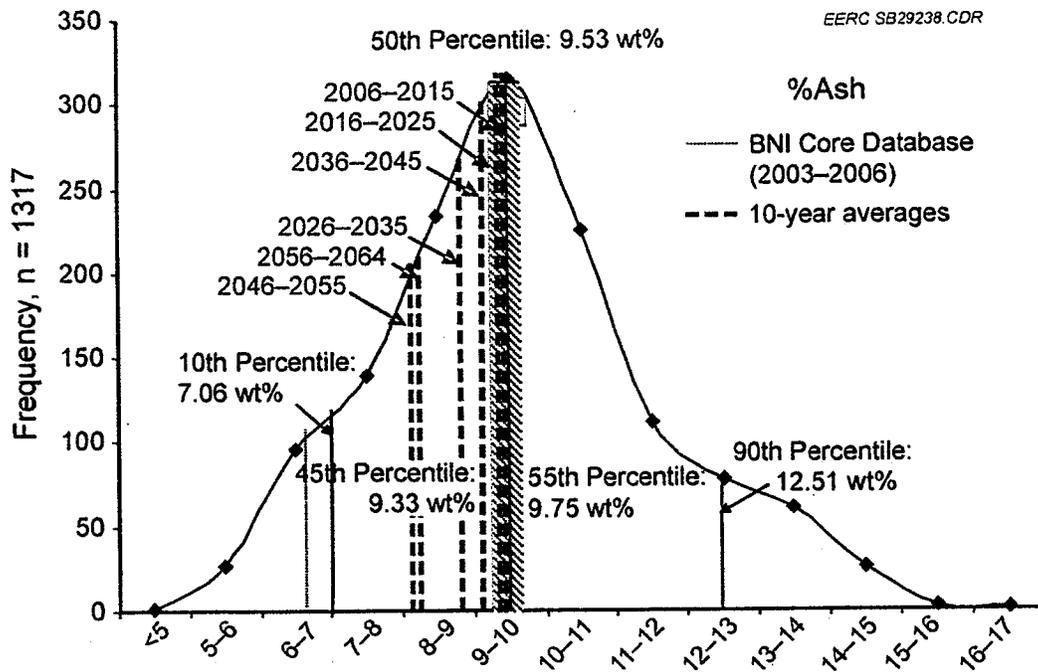


Figure 3. Ash frequency distribution for as-fired database compared to 10-year averages and weighted Core Database values.

Combustion Processes and Partitioning

The inorganic coal components undergo complex chemical and physical transformations during combustion to produce intermediate ash species in the form of inorganic vapors, liquids, and solids. The partitioning of the inorganic components during combustion to form ash intermediates depends upon the association and chemical characteristics of the inorganic components, the physical characteristics of the coal particles, the physical characteristics of the coal minerals, and the combustion conditions. The physical transformations involved in fly ash formation illustrated in Figure 4 include 1) coalescence of individual mineral grains within a char particle, 2) shedding of the ash particles from the surface of the chars, 3) incomplete coalescence due to disintegration of the char, 4) convective transport of ash from the char surface during devolatilization, 5) fragmentation of the inorganic mineral particles, 6) formation of cenospheres, and 7) vaporization and subsequent condensation of the inorganic components upon gas cooling. As a result of these interactions, the resulting ash composition and mass distribution as a function of size is also shown in Figure 4. Typical ash derived from coal combustion has a bimodal to multimodal size distribution that consists of a submicron and supermicron size fraction as shown in Figure 5. The submicron component is largely a result of the condensation of flame-volatilized inorganic components such as sodium. The intermediate size mode at about 2 micrometers is derived from the more refractory organically associated elements such as calcium and magnesium. The larger particles at approximately 12 to 15 μm are derived from the mineral grains present in the coal. The larger-size particles have been called the residual ash by some

investigators (Sarofim and others, 1977) because these ash particles resemble, to a limited degree, the original minerals in the coal. During the gas-cooling processes in the boiler, the gas-phase species condense and the liquid-phase materials solidify. The abundance of these gas-phase and liquid materials entrained in the bulk gas flow is highly dependent upon coal composition and system operating conditions.

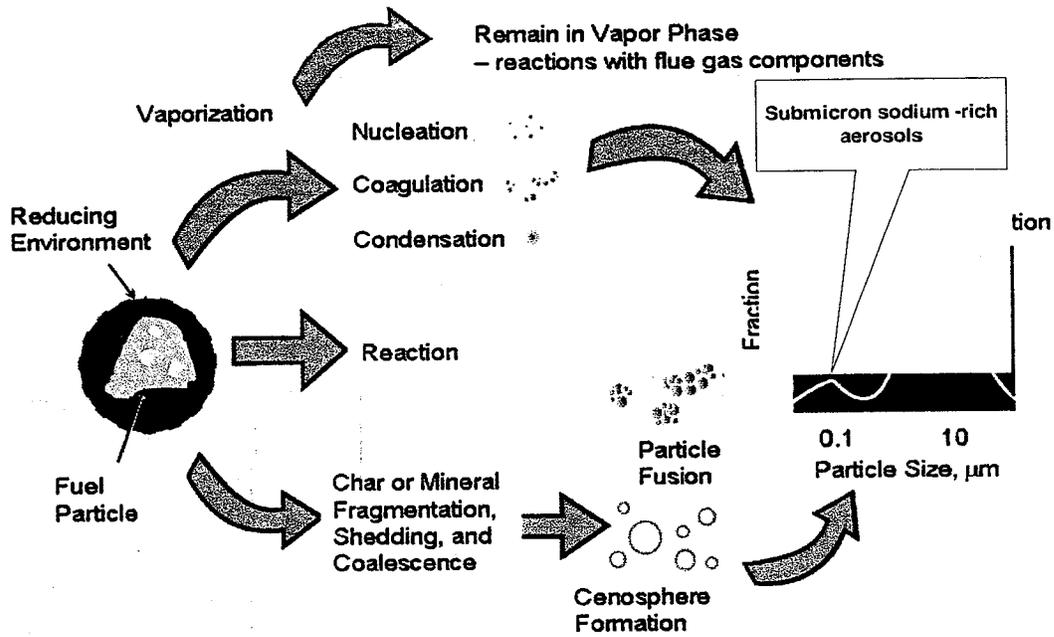


Figure 4. Transformation of inorganic components present in coal during combustion.

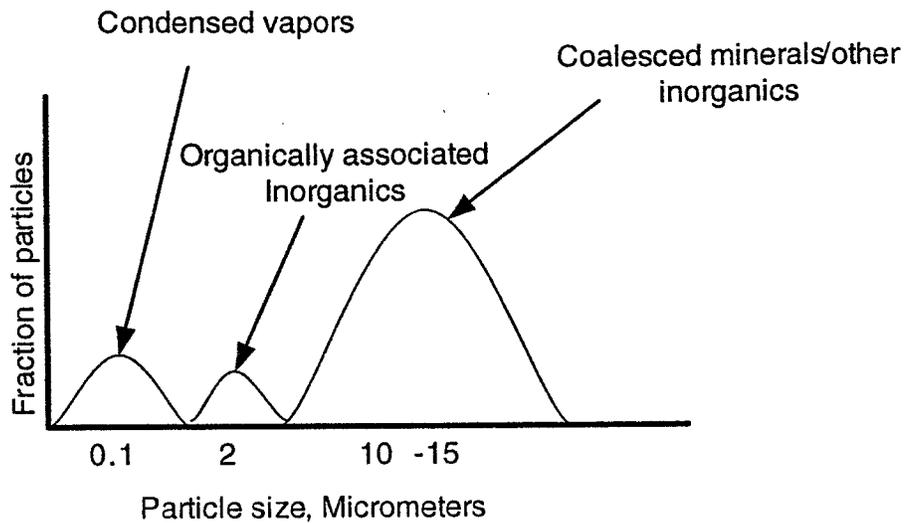


Figure 5. Final size distribution of ash particles produced upon combustion of lignitic coals (Benson and Laumb, 2007).

Cyclone fired systems enhance the partitioning of the inorganic components both by high temperatures and cyclonic action. The partitioning of sodium between the slag and coal is shown in Figure 6. The results show the sodium present in the as-fired coal ash presented with and without SO_3 . The retention of sulfur in the ash is an artifact of the ashing procedure. In comparing the level of sodium in the slag to the coal fired for the high-sodium cases, only about half of the sodium is retained in the slag. The slag samples were recovered from the slag tap for the boiler. These slag samples include deposits that fall from the walls and the high-temperature convective pass.

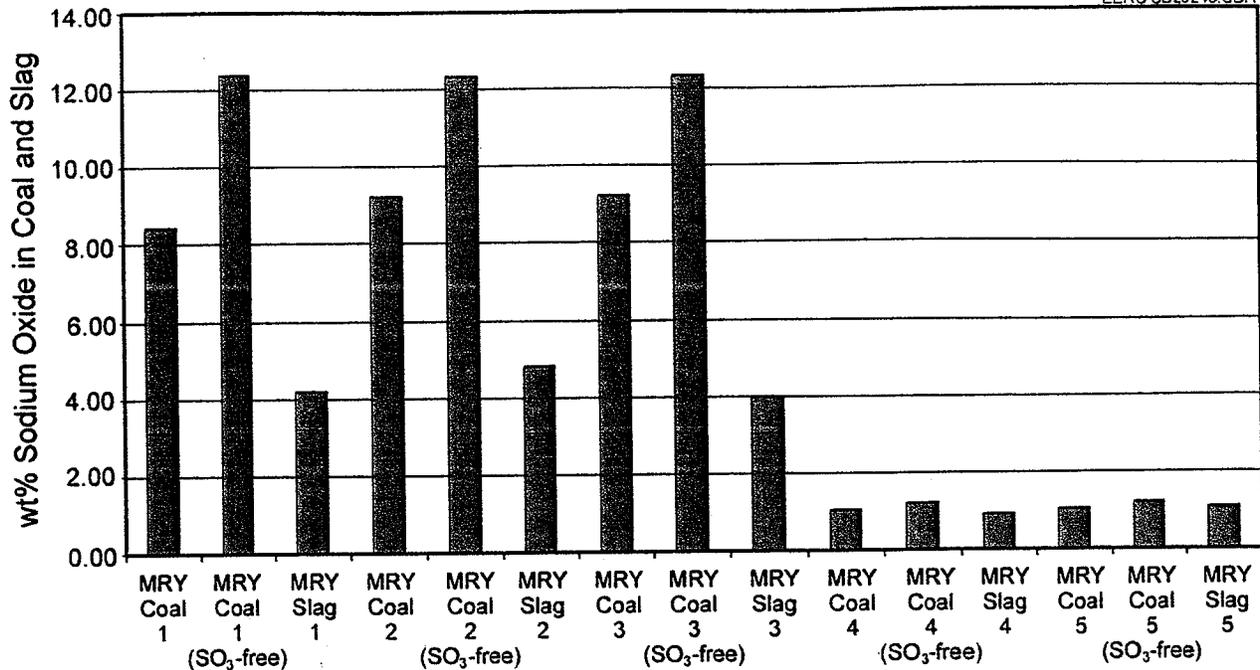


Figure 6. Comparison of sodium levels in Center lignite coal and slag samples.

The transport of intermediate ash species (i.e., inorganic vapors, liquids, and solids) to surfaces within a combustion system (combustion and air pollution control system) is a function of the state and size of the ash species and system conditions such as gas flow patterns, gas velocity, and temperature. Several processes are involved in the transport of ash particles to surfaces in the combustion system. These processes have been described in detail by Raask (1985) and Rosner (1986). The primary transport mechanisms are illustrated in Figure 7. For larger particles inertial impaction and eddy impaction in turbulent regions are the dominant mechanisms. The small particles (<1 μm) and vapor-phase species are transported by the vapor phase and small particle diffusion. The inorganic materials are transported to heat-transfer and catalyst surfaces by diffusion, electrophoresis, and inertial impaction. Thermophoresis is not a significant contributor to the transport of particles as it related to SCR materials. However, thermophoresis is a contributor to particle transport on heat transfer surfaces because of the temperature gradient.

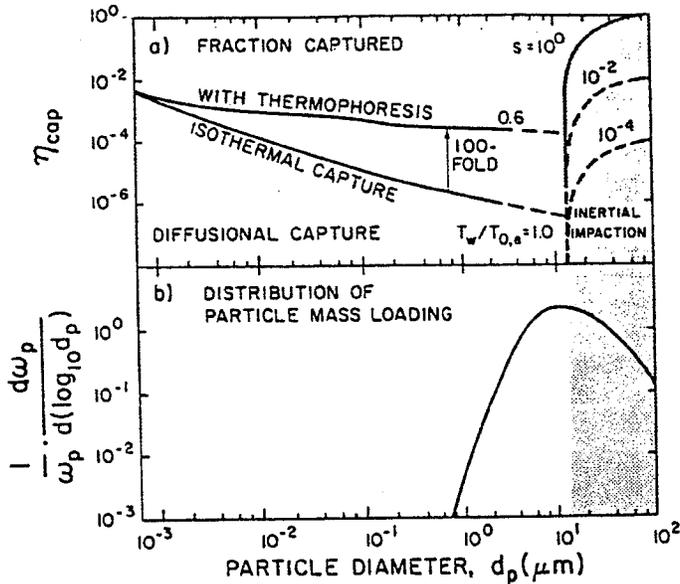


Figure 7. Overview of ash transport mechanisms (Rosner, 1986); (a) particle size dependence of captured fraction n_{cap} ; (b) size distribution of the mainstream particle mass loading. The accumulation rate will involve a combination of a and b.

The vapor phase and small particles are characteristically rich in flame-volatilized species that condense upon gas cooling in the bulk gas or in the gas boundary layer next to the surface. The diffusion mechanisms important with respect to the transport of vapor species and small particles to the surface of SCR catalysts include:

1. Fick diffusion – molecular level.
2. Brownian diffusion – particles suspended by a host liquid.
3. Eddy diffusion – turbulent systems.

SCR Catalyst Characteristics and Properties

SCR catalysts for coal combustion applications consist of ceramic material with high porosity that contains imbedded active catalytic sites. The NO_x reduction occurs on the active surface of the catalyst. The active surface of the catalyst consists of flat surfaces and pores within the flat surface of the catalyst. The flat surfaces and pores in the catalyst are designed to provide gas contact with the active surface of the catalyst. The pores consist of open macropores and micropores that occur on the surface of the catalyst structures.

The size of the openings in honey comb catalyst impacts the velocity of the gases flowing through the catalyst. Pitch is the term used to describe the openings between the flat surfaces of the catalyst. Figure 8 illustrates the pitch, p and the wall thickness, a . Lower gas velocities will result for higher pitch numbers while small numbers will result in higher gas velocities through the catalyst. Catalyst vendors have methods to identify the proper pitch for specific fuel types and ash characteristics to minimize bridging or plugging where the dominant transport mechanism is inertial impaction and eddy impaction for the large particles. Selecting a pitch that

will minimize the transport of small particles and vapor phase species is not as straightforward. High pitch catalysts will result in lower velocity gas flow through the catalyst and will create a thicker boundary layer resulting in an increased potential for small particle transport. Catalyst geometry plays a significant impact on gas flow patterns through the catalyst. Evaluation of the literature and information provided by catalyst vendors indicate that the geometries of catalysts have not been improved to minimize small particle and vapor phase deposition on the surface and within the pores of catalyst (Hansen, 2007).

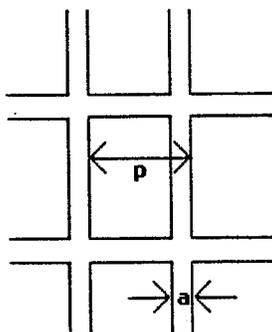


Figure 8. Catalyst pitch (Mussatti, 2002).

An example of the macropore structure is shown in Figure 9 for an actual surface for a honeycomb type catalyst. The openings in the catalysts create porosity and surface area to expose the reactive components of the catalyst to gas phase components. These openings are prone to filling with small particles and large particles through the transport processes of diffusion and impaction, respectively. Once these particles are transported to the surfaces they will be held in place by weak electrostatic and van der Waals forces and they will react with vapor phase sulfur oxide species.

Chemical and physical mechanisms of pore plugging

The most significant problems that limit the successful application of SCR catalysts to lignite coal is the formation of low-temperature sodium–calcium–magnesium sulfates that will form on the surfaces of catalysts and the carryover of deposits that will plug the catalyst openings, resulting in increased pressure drop and decreased efficiency. Studies conducted at Coyote station (Benson and others, 2005) found significant blinding and filling of the pores with small particles as shown in Figure 9. Rapid filling of the pores occurred with the catalyst pitch of 6 mm. These materials were subjected to air pulsing that did not remove the materials from the catalyst. The characteristics of the materials filling the pore were rich in sodium and calcium sulfates. A high magnification image of the materials coating the catalyst and filling the pore is shown in Figure 10. This image shows the importance of the very small particles less than 1 micrometer and their impact on the bonding of the deposited materials. These small particles readily interact with gas phase SO_2 and SO_3 expanding to create a bonded matrix as shown in Figure 11 that completely fills the pores of the catalyst with a continuous bonded phase. A high magnification cross-section is shown in Figure 12 of a highly sulfated bonded matrix.

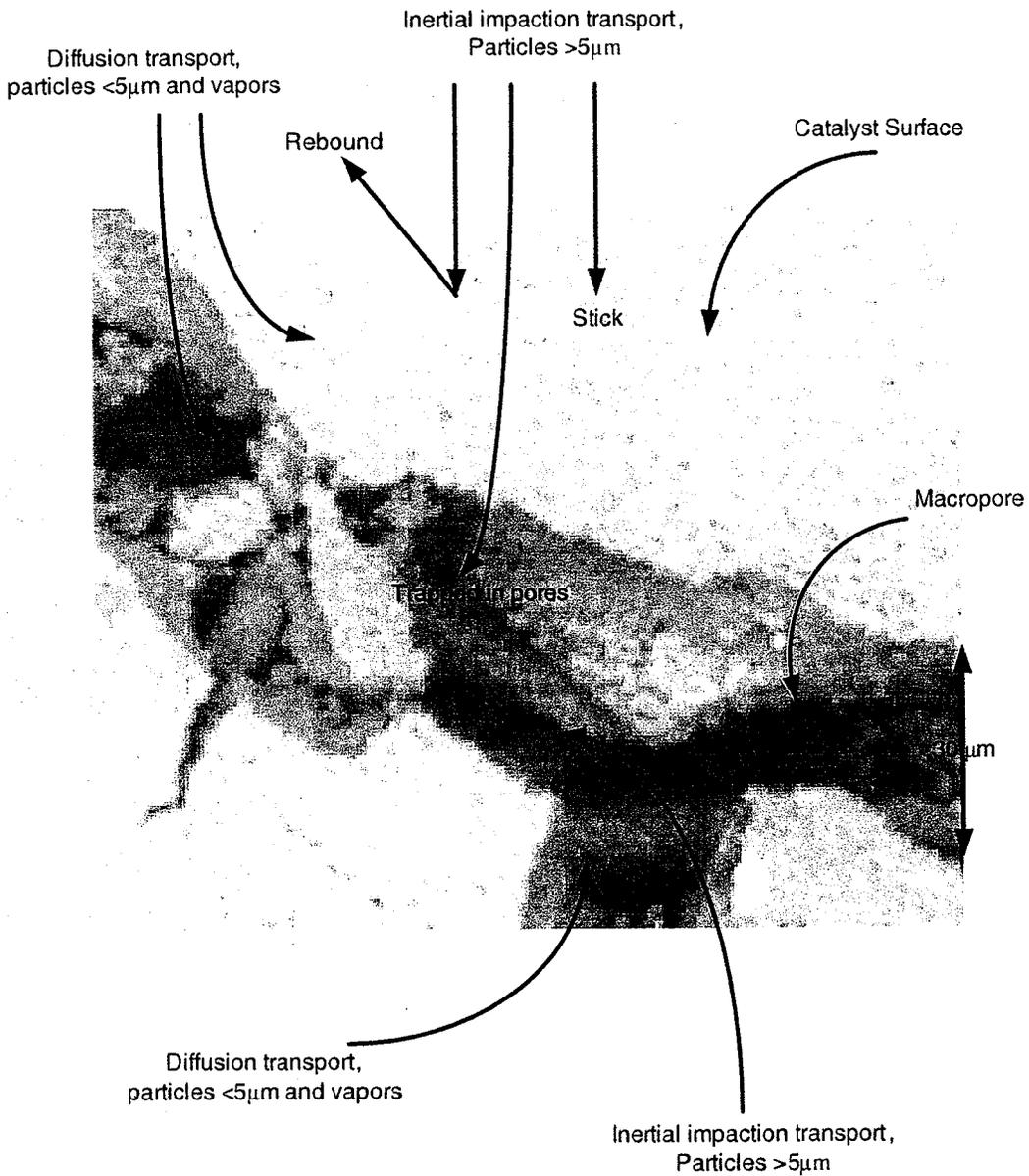


Figure 9. Scanning electron microscope secondary electron image of the macropore structure of an SCR catalyst with transport process descriptions.

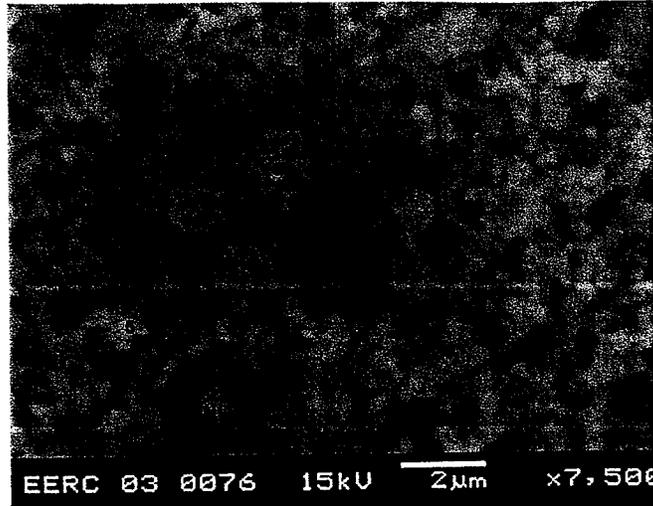


Figure 10. High magnification secondary electron image of ash filling pores and covering catalysts.

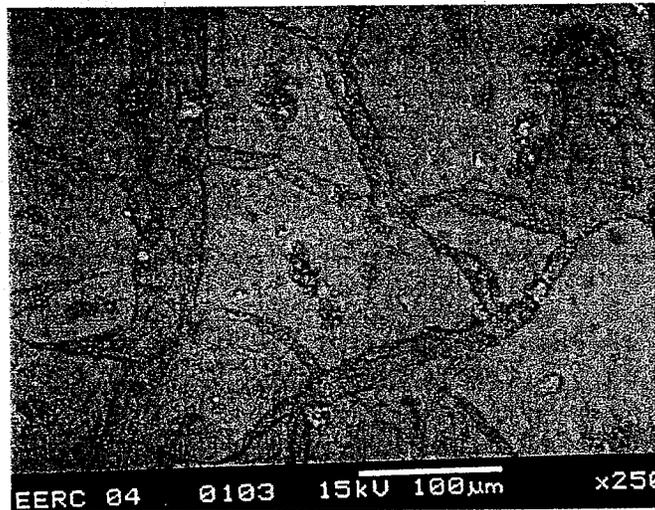


Figure 11. Scanning electron microscopy image of ash materials filling the pores of catalyst exposed to flue gases derived from the firing of Beulah lignite at Coyote Stations (Benson and others, 2005).

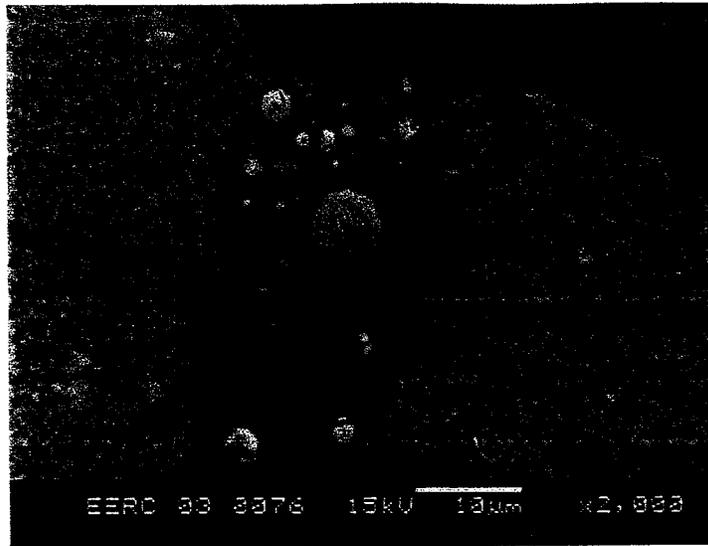


Figure 12. High magnification image of materials typical of ash filling pores that has sulfated and bonded.

Pyrosulfates are present in ash deposits and will likely form in SCR catalysts. Melting points for pyrosulfates between 535° and 770°F have been reported in the literature (Singer, 1981). Much of the past work has focused on the formation of these phases on tube surfaces. These species contribute to the corrosion of heat-transfer surfaces in coal-fired power plants. The exact melting point depends on the relative amounts of sodium and/or potassium. The melting points of selected pyrosulfate phases are shown in Table 2.

The formation of pyrosulfates involves the following processes

1. Formation of sulfates such as Na_2SO_4 and K_2SO_4
2. Conversion of SO_2 to SO_3 in the bulk gas phase – catalytically active surface such as an SCR catalyst – $\text{SO}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{SO}_3$
3. Pyrosulfate formation – $\text{Na}_2\text{SO}_4 + \text{SO}_3 \rightarrow \text{Na}_2\text{S}_2\text{O}_7$

A diagram depicting the physical and chemical reactions involved in the filling and plugging of catalyst pores is shown in Figure 13 (Benson and others, 2005).

Table 2. Melting Points of Selected Pyrosulfate Compounds

A. Compound	Temperature, °C	Temperature, °F
$K_3Fe(SO_4)_3$	618	1144
$K_3Al(SO_4)_3$	654	1209
$KFe(SO_4)_2$	694	1281
$Na_3Fe(SO_4)_3$	624	1155
$Na_3Al(SO_4)_3$	646	1195
$NaFe(SO_4)_2$	690	1274
$Na_2S_2O_7$	401	754
$K_2S_2O_7$	300	572
$(K_{1.5}Na_{0.5})S_2O_7$	279	535

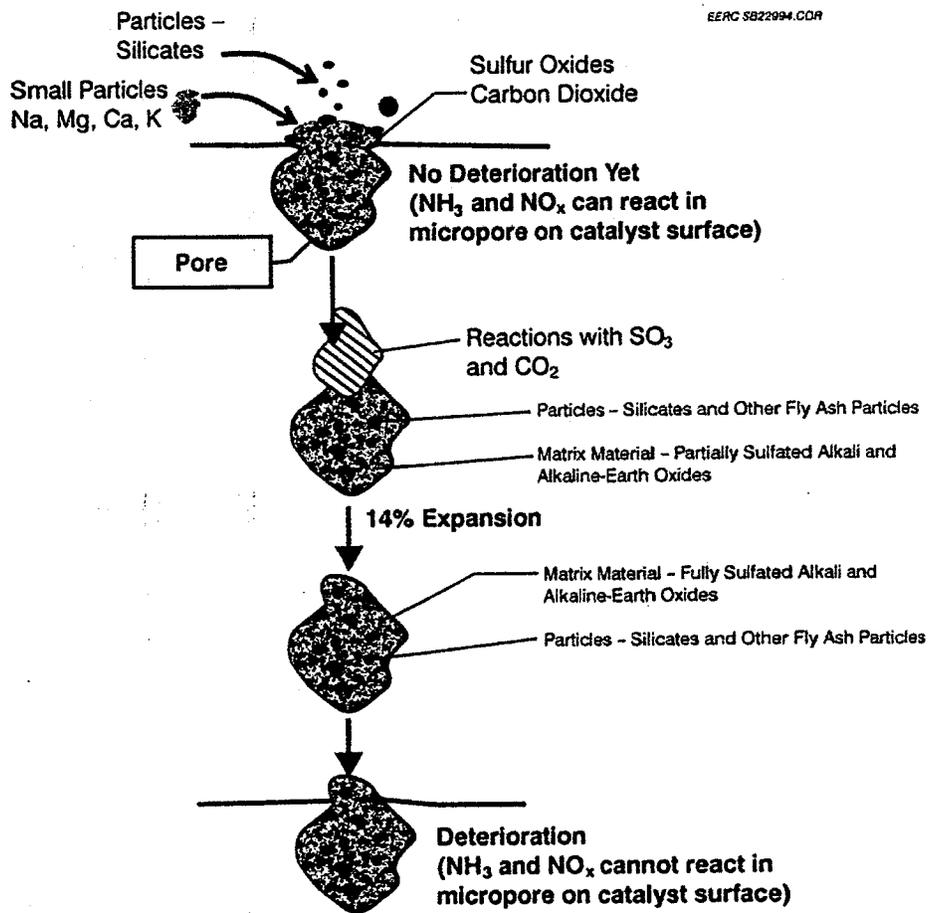


Figure 13. Overall mechanism of SCR Catalyst blinding (modified after Pritchard and others (1995)).

Table 3. Comparative Alkali Content Analysis for U.S. Coals (Singer, 1981)

Rank Region	Lignite ND	Sub B MT	Lignite TX (Yegua)	Lignite TX (Wilcox)	hvBb UT	hvAb PA	Lignite TX (Wilcox)
HHV, Btu/lb, Dry Basis	10640	12130	7750	9710	12870	13200	8420
Ash Composition (%)							
SiO ₂	20.0	33.9	62.1	52.3	52.5	51.1	57.9
Al ₂ O ₃	9.1	11.4	15.1	17.4	18.9	30.7	21.8
Fe ₂ O ₃	10.3	10.8	3.5	5.3	1.1	10.0	3.9
CaO	22.4	21.0	6.2	9.4	13.2	1.6	7.1
MgO	6.4	2.7	0.7	3.2	1.3	0.9	2.1
Na ₂ O	5.0	5.8	3.6	0.9	3.8	0.4	0.7
K ₂ O	0.5	1.6	1.9	1.2	0.9	1.7	0.8
TiO	0.4	0.7	0.9	1.2	1.2	2.0	1.1
SO ₃	21.9	12.0	6.1	9.6	6.2	1.4	4.4
Fouling Potential	Severe	High	High	Moderate	Moderate	Low	Low
<hr/>							
Lb Ash/10⁶ Btu, Dry Basis	9.0	4.6	43.3	20.1	7.9	10.2	34.4
Acetic-Acid-Soluble							
Sodium (Na, ppm)	3980	2680	9650	1030	1120	250	340
Potassium (K, ppm)	1230	85	85	...	110
Alkali in Ash, % Wt.							
Na ₂ O	5.0	5.8	3.6	0.9	3.8	0.4	0.7
K ₂ O	0.5	1.6	1.9	1.2	0.9	1.7	0.8
Equiv. Sol. Alkali in Ash, % Wt. of Ash							
Na ₂ O	5.58	6.45	3.88	0.71	1.49	0.15	0.16
K ₂ O	0.44	0.04	0.08	...	0.05
% Sol. Alkali of Total (Equiv. Sol. Na₂O)/(Na₂O in Ash)							
	112	111	108	79	39	38	23
(Lbs Sol. Na)/(10⁶ Btu Fired)							
	0.374	0.221	1.245	0.106	0.087	0.018	.040
(Lbs Sol. Na)/(lb Ash/10⁶ Btu Fired)							
	0.044	0.048	0.223	0.005	0.014	0.002	0.001

The following summarizes the state-of-the-art relative to the application of SCR for use in high sodium lignite combustion systems such as at the MRY plant.

- Coal properties
 - Center lignite coal contains organically associated sodium, magnesium and calcium
 - The levels of sodium in the Center lignite will remain constant and will likely increase in the future years
- Ash formation
 - Sodium vaporizes during combustion to form very small particles
 - Sodium is in a soluble form

- Catalyst properties
 - Catalysts have high porosity in the form of macropores and micropores that have active components dispersed within them allowing for NO_x reduction reaction
 - Pitch of the catalyst appears to be the only change in geometry available to minimize deposition
 - Catalyst are prone to deactivation because of the presence of soluble sodium
- Ash transport in SCR catalyst
 - Ash particle transport mechanisms are dependent upon gas velocity
 - Particles greater than approximately 10 micrometers are transported to the surfaces of catalysts by inertial impaction mechanisms
 - Vapor phase and small particles are transported through diffusion processes into the pores of the catalyst across the stagnant gas boundary layer next to the surface
 - Small ash particles rich in sodium, calcium, and sulfur infiltrate deep into the catalyst pores causing blinding and plugging and possibly deactivation

The following are changes that could be made in future pilot testing and, based on the previously presented information, the impacts of those changes that could reasonably be anticipated to occur.

- Test catalysts with larger openings (greater Pitch)

Impacts: The current recommendation (for the coal-fired industry in general) by catalyst vendors is to use catalysts that have a larger pitch. Using catalysts with a larger pitch will likely decrease the velocity through the catalyst and decrease the impaction rates of the larger particles. However, this does not address the key problem of vapor phase and small particle diffusion into the pores of the catalysts that is associated with the combustion of high sodium Center lignite. By decreasing the velocity, the gas boundary layer may be larger resulting in an increase in the diffusion processes resulting in increased deposition of the smaller particles into the pores. In addition, decreasing gas velocity will decrease the scrubbing action of impacting particles that aids in removing deposited ash particles.

- Test catalyst with modified pore structure that does not accumulate small particles

Impacts: The use of these catalysts should have a positive impact on reducing catalyst poisoning and pore plugging. However, discussions with catalyst vendors and literature searches indicate that little or no work has been conducted on such formulations. Most of the work being conducted by catalyst vendors is focused on reducing SO₃ production and enhancements for mercury oxidation. As a result, these catalysts are not available.

- Enhanced cleaning technologies for removal of particles in the pores of catalysts

Impacts: The use of acoustic horns appears to clean the surfaces as well as sootblowers on subbituminous and bituminous fueled boilers. However, this

technology has not been demonstrated on lignite fueled boilers. There is significant uncertainty in the ability of acoustic horns to clean the ash particles from the pores of the catalyst.

There does not appear to be a catalyst material that has shown significantly improvement over the past catalyst relative to the performance in high sodium containing system. The specific question was asked to Flemming Hansen (Hansen, 2007) as to whether improvements have been made in catalysts over the ones tested at Coyote station that warrant further testing. He indicated that no formulation or design changes have been made to improve their performance in high sodium containing flue gases.

The testing at Coyote station indicated that the macropores and the catalyst openings were plugged. The blinding of the catalyst from the Coyote station testing was so severe that the catalyst vendor could not make deactivation measurements. Cleaning the catalyst and measuring deactivation was not performed based on recommendation of the catalyst vendor. The reason for not cleaning and conducting the measurements were based on concerns expressed by the vendor that the results of such deactivation testing after cleaning would not provide meaningful data on deactivation rates.

At the present time, there is not sufficient evidence to indicate that further pilot testing, even though it could be significantly reconfigured from previous testing, would yield significantly different results from that of testing already conducted at the Coyote station. Additionally, there is nothing to suggest that further testing would necessarily result in catalyst samples being made available that would allow for the measurement of deactivation rates.

SCHEDULE BASIS FOR MINNKOTA'S DECISION NOT TO CONDUCT PILOT SCR TESTING

The CD requires that compliance with the "30-day Rolling Average NO_x Emission Rate" established as BACT in accordance with the CD be achieved for Unit 2 at MRYS not later than December 31, 2010. For the hypothetical case in which an SCR pilot test were conducted to potentially establish the technical basis for SCR application to the Units at MRYS, the following tasks would need to be completed prior to this date:

1. Design the SCR pilot test protocol and obtain concurrence of NDDH and EPA
2. Design, procure and install the pilot SCR
3. Conduct the SCR pilot testing and evaluate the results
4. Conduct a technical feasibility analysis of the boiler modifications that would be necessary for Units 1 and 2 to allow reduction of flue gas temperatures (which are currently well above the required range for SCR operation, as previously documented in Minnkota's submittals to NDDH) while maintaining the ability to dry the lignite as required for combustion.
5. Revise the BACT analysis based on the results of Steps 3 and 4 (hypothetically assuming that they concluded it was technically possible to install SCR) to establish the revised "30-day Rolling Average NO_x Emission Rate" based on the hypothetical use of SCR.

6. Receive the final determination from NDDH regarding the "30-day Rolling Average NO_x Emission Rate" representing BACT in accordance with the CD.
7. Incorporate the results of steps 3 through 6 (hypothetically assuming that they concluded it was technically possible to install SCR and established an SCR-based value for the "30-day Rolling Average NO_x Emission Rate") into a procurement specification for the SCR system in accordance with RUS requirements.
8. Procure the SCR system on a "furnish and erect" basis, obtaining a vendor guarantee that assured compliance with the BACT emission limit as set forth in Step 6.
9. Design, fabricate, and erect the SCR systems and the necessary boiler modifications, using the Contractor selected in Step 8.
10. Start-up and commission the SCR system for Unit 2 and achieve stable performance to allow continuous compliance with the BACT emission limit as set forth in Step 6.

Based on Burns & McDonnell's evaluation, the time required to complete these tasks would be approximately 65 months from initiation of Task 1. Thus it would not be possible to comply with the CD date certain of December 31, 2010 for compliance with the "30-day Rolling Average NO_x Emission Rate" established as BACT in accordance with the CD.

The estimate of 65 months duration to complete this process is based on the following assumptions for the duration of the individual steps:

Step 1 is assumed to require two months. It should be noted that the EPA and its consultants have claimed that the previous SCR pilot testing at Coyote was fundamentally flawed. Thus it is essential that this step be thoroughly and carefully conducted and documented in order to assure the "buy in" of the interested parties.

Step 2 is estimated to require six months.

Step 3 is estimated to require 24 months. It is believed that the collection of 18 months of data will be necessary to properly evaluate the technical feasibility of SCR at MRYS. Due to the operating characteristics of the Units and based on prior experience with pilot testing, it is believed that the duration of pilot testing needed to acquire 18 months of data will be 24 months.

Step 4 is estimated to require six months, based on consultation with the boiler OEM. It should be noted that although Step 4 is assumed to be performed concurrently with Steps 1 through 3, all other steps must be conducted sequentially. Also, it should be noted that the subsequent sequence is based on the hypothetical assumption that the results of Steps 3 and 4 are favorable to the technical feasibility of SCR.

Steps 5 and 6 are estimated to require two months each. Because no SCR vendor has experience with SCR operation on North Dakota lignite, the determination of an emission rate corresponding to the hypothetical use of SCR will require the dissemination of the pilot test results from the catalyst vendors (which are assumed to be active participants in the pilot SCR program) to the SCR system suppliers. This is because the establishment of a NO_x emission rate representing BACT will require at least a preliminary indication from the system suppliers that such a level can be guaranteed. It is assumed that the system suppliers will guarantee the

emission rate established in Step 6, and will otherwise respond favorably to the procurement process in Step 8.

The development of the technical specifications for the SCR procurement contract (Step 7) is estimated to require two months. The specifications must incorporate not only the results of the pilot SCR testing from Step 3 but the boiler modifications identified in the study conducted in Step 4. Again, the sequence assumes that it will be possible to find a feasible way of modifying the boilers to simultaneously achieve the flue gas temperature range required for SCR operation while continuing to achieve proper pre-drying of the lignite.

The period for bidding and award of the SCR contract (Step 8) is estimated to be four months. Typical bid period for a complex "furnish and erect" SCR retrofit contract such as this will be three months. One month is assumed for evaluation and negotiation.

For Step 9 it has been assumed that the period from award of the SCR contract to the completion of erection and tie-in will be 20 months. It is anticipated that the duration of construction of an SCR system in North Dakota will require somewhat longer than would be expected for other parts of the country due to the severity of the winter. Also, depending upon the complexity of the required boiler modifications, the construction period can be expected to be extended compared to a "typical" SCR project schedule which does not include the need for extensive boiler modifications.

The startup, commissioning and tuning of the SCR system (Step 10) has been estimated to require three months. It should be noted that concerns with the characteristics of the fly ash are anticipated to extend the time that would routinely be required for this step. Also, unlike most retrofit SCR projects completed to date in the U.S., this installation would be subject to a "not to exceed" emission limitation on a 30-day rolling average. Assurance that the limit could be continuously met would require more than the usual extent of operational tuning.

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