Recent Dual Flue Gas Conditioning Experience

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ABSTRACT

For the past 25 years Flue Gas Conditioning (FGC) systems have been installed principally to improve the performance of precipitators that failed to achieve design expectations while burning low sulfur coal. In the last few years FGC has been applied in the United States as a cost effective strategy to comply with Phase 1 of the Clean Air Act of 1990. More recently many plants have purchased FGC systems to enable use of low cost, low sulfur coals. The use of western coals such as those from the Powder River Basin has been moving further east every year. In addition the use of foreign coal, such as South African and Venezuelan coal, has also become more common in the U.S.

In April 1992 Georgia Power purchased 15 Chemithon sulfur trioxide (SO_3) FGC systems as part of their fuel switching strategy to comply with Phases I and II of the 1990 Clean Air Act. After switching to a lower cost, low sulfur coal last year Plant Yates was unable to consistently achieve 20% maximum opacity without periodic boiler derates, even with SO_3 FGC. Based on coal and ash analyses of the new fuel, Chemithon determined that dual conditioning with ammonia and sulfur trioxide could restore precipitator performance to levels before the coal switch. This paper describes the cost effective upgrade to dual conditioning and performance of the dual conditioning system that Georgia Power purchased for Plant Yates Unit 5.

INTRODUCTION

The history of flue gas conditioning dates back almost as far as the first electrostatic precipitator (ESP). As early as 1912, experimental work at the Garfield, Utah smelter indicated that increasing levels of SO_3 in smelter converter gases increased the collection efficiency of the ESP. The work demonstrated that many non-conductive dusts and fumes could be made collectable by adding SO_3 and/or moisture to the gas stream ahead of the ESP. Since that time, many other substances have been used to condition flue gases. These include: ammonia, triethylamine, and various proprietary chemicals. SO_3 is still the predominate conditioning agent for high resistivity ash.

For pulverized coal fired furnaces, reducing fuel sulfur below design levels frequently causes difficulties for ESPs. The performance of an ESP is sensitive to the physical properties of the flue gases and fly ash particles, particularly ash resistivity. High fly ash resistivities, above about 1×10^{10} ohm-cm, may result in decreased collection efficiencies. This problem can generally be reversed by injecting SO_3 upstream from the ESP. The SO_3 condenses on the particulate, improving its ability to accept and release an electrical charge.

In some cases of high ash resistivity, sulfur trioxide flue gas conditioning alone is not effective. Some of these are:

1. The fly ash does not absorb the sulfur trioxide. This is generally true of fly ash that has a combined silica-alumina content of more than 90% and a low concentration of alkali metals. These ashes are frequently referred to as acidic ashes.
2. Flue gas temperatures are too high for the sulfur trioxide to attach to the ash. This can be as low as 320°F (160°C) and depends on ash composition and gas moisture.
3. High precipitator gas velocities. The performance improvement from lowering ash resistivity is offset by increased reentrainment due to lower ‘holding forces.’
4. High unburned carbon carryover in the ash. The carbon particles do not hold a charge. In addition they are extremely fine and will increase the stack opacity without a proportional increase in mass loading. When the carbon carryover exceeds about 10%, reentrainment becomes a severe problem.

The simultaneous and independent injection of both ammonia and sulfur trioxide referred to as dual gas conditioning can be an effective solution to these problems. Ammonia gas conditioning has been used by the petroleum industry to treat catalyst dust since about 1940. In addition ammonia alone has been used on boilers firing high sulfur coal for many years to improve precipitator performance, reduce the acid dew point and corrosion, and in some cases eliminate the 'blue plume' from high sulfur trioxide emissions.

Ammonia injected into flue gas in the presence of sulfur trioxide and flue gas moisture reacts to form many ammonia compounds, principally ammonium sulfate and bisulfate compounds. These particles nucleate on sub micron particulate in the gas stream and help to agglomerate and increase ash particle size. The ammonia also reacts with 'acidic' ash to facilitate absorption of sulfur trioxide. The resulting ammonium bisulfate is a sticky compound above its melting point of about 290°F. It is believed to help agglomerate the ash and improve the ash cohesivity. Another observed effect is an increase in the flow of ions, electrons and charged particulate in the inter-electrode space, or space charge.

Precipitators with high gas velocities sometimes do not benefit from reductions in ash resistivity. The lower ash resistivity enables the ash to more readily release its charge to the collecting plate, reducing the electrostatic holding force. The reduced holding force allows more ash to reentrain into the gas stream when the collecting plates are rapped. The improvement in ash cohesivity from dual conditioning reduces rapper reentrainment by agglomerating ash on the collecting plates.

Recently many utilities have switched to low sulfur fuel and converted to low NO_X burners. The low NO_X burners frequently cause an increase in the unburned carbon particles. The unburned carbon—coupled with the lower sulfur trioxide concentrations from the lower sulfur coal —presents a difficult collection problem. The resultant ash is a mixture of high resistivity particles and low resistivity carbon particles. The lower resistivity particulate readily reentrains into the gas stream. In addition, the low resistivity particulate tends to reduce the maximum field strength and prevents charging of the high resistivity ash. Injecting sulfur trioxide alone improves the capability to charge the high resistivity ash but the benefit is often offset by increased reentrainment of the carbon particles.

Dual injection overcomes this problem by reacting the carbon particles to form various ammonia-sulfate based compounds, which agglomerate the carbon particles and increase ash cohesivity. This reduces reentrainment, and allows an increase in the sulfur trioxide concentration which in turn reduces ash resistivity.

Based on the ash analysis of the new low sulfur fuel and experience with sulfur trioxide FGC systems, we believed that dual conditioning would improve the electrostatic precipitator performance at Plant Yates. To reduce cost and improve the functionality of the system the dual FGC system supplied at Plant Yates for Unit 5 was integrated into the present sulfur trioxide FGC system utilizing existing components where possible. The result was that the ammonia system was much less expensive than traditional, stand-alone ammonia systems and offers complete integration into the existing FGC system.

Description of Georgia Power Plant Yates

Georgia Power Plant Yates is located near Newnan, Georgia. The plant has seven coal fired units of the following capacities: Units 1 through 3 are 100 mW; Units 4 and 5 are 125 mW; and Units 6 and 7 are 350 mW. All except Unit 1 have a Chemithon sulfur trioxide FGC system of 25 ppm capability. Unit 1 has a Chiyoda scrubber. Units 4 and 5 share a common stack.

Low NO_X burners were installed in the spring of 1995. Based on guarantee test data taken before and after the NO_X burner retrofit, the carbon carryover or LOI increased from about 2 to 3% to about 4 to 5% after installation. The low NO_X retrofit consisted of new International Combustion Limited model MK III Flame attached nozzle burners and the addition of secondary air.

The plant typically burns a variety of coals. These are predominately low sulfur Virginia coals supplied by Arch Coal Company and Delta Pardee Coal company.

Description of Unit 5 Electrostatic Precipitator

Unit 5's Buell precipitator, installed in 1968, treats 550,000 ACFM at 305°F. It is a weighted wire design of two chambers and three mechanical and five electrical fields. Plate spacing is 9 inches. Design gas velocity is 4.97 feet per second. The SCA is approximately 188. Precipitator design particulate removal efficiency is 98.3%. Typical full load opacity on high sulfur coal before installation of the low NO_X burners and the FGC equipment was about 21%.

Mingo Logan Coal

In order to reduce fuel costs, Plant Yates started burning Mingo Logan fuel, from Mingo County West Virginia in the spring of 1995. The fuel has about 0.7% sulfur and about 12,750 Btus/lb. (as received). Table 1 contains a summary of the typical coal and ash analysis. The ash produced from this coal is low in calcium and has a silica plus alumina content of about 84%. It differs principally from most of the other fuels typically burned at Plant Yates in that the iron oxide content is less than 5%.

Ultimate Analysis (as received):	
Moisture %	4.450
Carbon %	75.640
Hydrogen %	4.610
Nitrogen %	1.360
Sulfur %	0.660
Ash %	9.430
Oxygen %	3.860
Ash Analysis:	
SiO_2 %	55.70
Al_2O_3 %	27.06
TIO_2 %	1.65
FE_2O_3 %	4.93
CAO %	1.22
MGO %	0.98
NA_2O %	0.95
K_2O %	2.00
P_2O_5 %	0.18
SO_3 %	0.52

Table 1. Mingo Logan Coal and Ash Analysis

Within a few weeks of burning this coal the plant was not able to maintain less than 20% opacity at all times. It was difficult to stay in compliance and at times boiler load was reduced. Increasing the sulfur trioxide treat rate did not help. In fact it was difficult to determine if sulfur trioxide FGC improved precipitator performance at all.

In March 1995 Georgia Power sent Chemithon several ash analyses of different fuels they were considering. Of these fuels, the computer resistivity model indicated that the Mingo Logan fuel would not condition well with sulfur trioxide and might have excessive unreacted sulfur trioxide emissions, or 'slip.' The ash from the Mingo Logan fuel as shown in Table 1 has a silica and alumina content of about 85% with low iron and very low calcium, about 1%. Experience has shown that high silica and alumina ash with a low concentration of alkali elements such as calcium do not absorb sulfur trioxide well. This problem becomes more pronounced at higher precipitator gas temperatures. Figure 1 is a resistivity curve for the Mingo Logan coal ash. Note that the sulfur trioxide equilibrium curves are steep and that above about 340°F adding sulfur trioxide does not decrease the resistivity. Table 2 contains coal and ash analysis of the other predominate low sulfur coals burned at Plant Yates. Figure 2 is a resistivity curve based on the ash analysis of the Arch/Lone Mountain coal. Although the ash analysis is very similar to the Mingo Logan in that it has a high alumina/ silica ratio and low calcium it has considerably more iron. When iron concentrations are less than about 5% with low calcium the 'Bickelhaupt' resistivity model tends to generate steep sulfur trioxide equilibrium curves. Our experience shows that coal ash with very low calcium and other alkali metals may not condition well with sulfur trioxide alone regardless of the iron concentration.

Ultimate Analysis (as received):	Arch/Lone Mountain	Delta/ Pardee	Massey
Moisture %	6.46	6.01	5.98
Carbon %	74.79	72.08	71.90
Hydrogen %	4.90	4.70	5.05
Nitrogen %	1.37	1.35	1.40
Sulfur %	.73	1.22	.88
Ash %	5.05	4.29	4.10
Oxygen %	6.71	10.35	10.91

Ash Analysis:	Arch/Lone Mountain	Delta/ Pardee	Massey
SiO_2 %	55.83	50.08	52.92
Al_2O_3 %	28.67	28.44	30.32
TIO_2 %	1.29	1.37	2.14
FE_2O_3 %	7.58	10.50	4.99
CAO %	2.56	1.23	1.05
MGO %	1.64	1.13	.80
NA_2O %	1.00	.84	.28
K_2O %	2.23	2.46	2.16
P_2O_5 %	.37	.55	.95
SO_3 %	1.50	.37	.42

Table 2. Analyses of Other Coals Used by Plant Yates

Dual Flue Gas Conditioning System Upgrade

The upgrade to dual flue gas conditioning consisted of anhydrous ammonia storage and vaporization equipment, ammonia metering, an ammonia/air mixer, and ammonia injectors. Figure 3 is a simplified P&ID of the process. The existing process air blower on the sulfur trioxide gas generator skid provided the air to convey and distribute the ammonia to the injectors. The ammonia is stored in a leased 1000 gallon tank. The ammonia/air mixture is injected through 12 injectors located downstream of the air heater and upstream of the sulfur trioxide injectors.

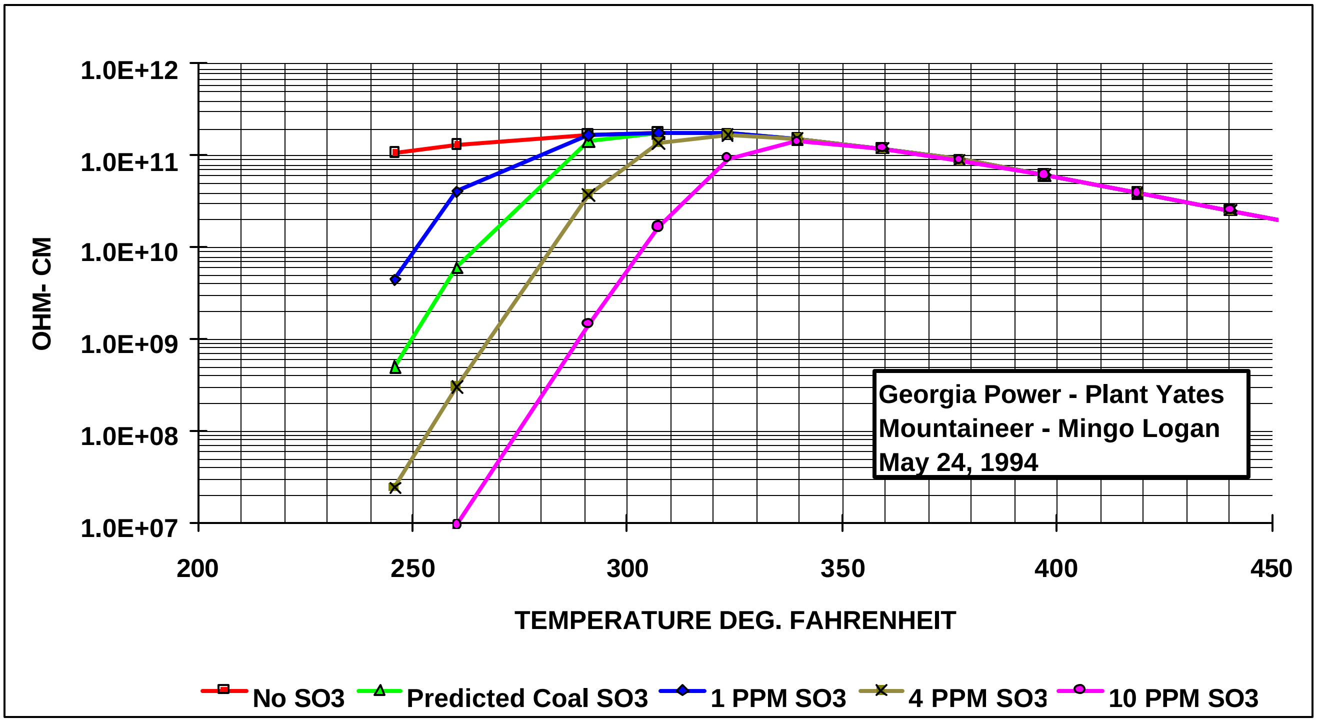

Figure 1. Ash Resistivity, Mountaineer - Mingo Logan Coal

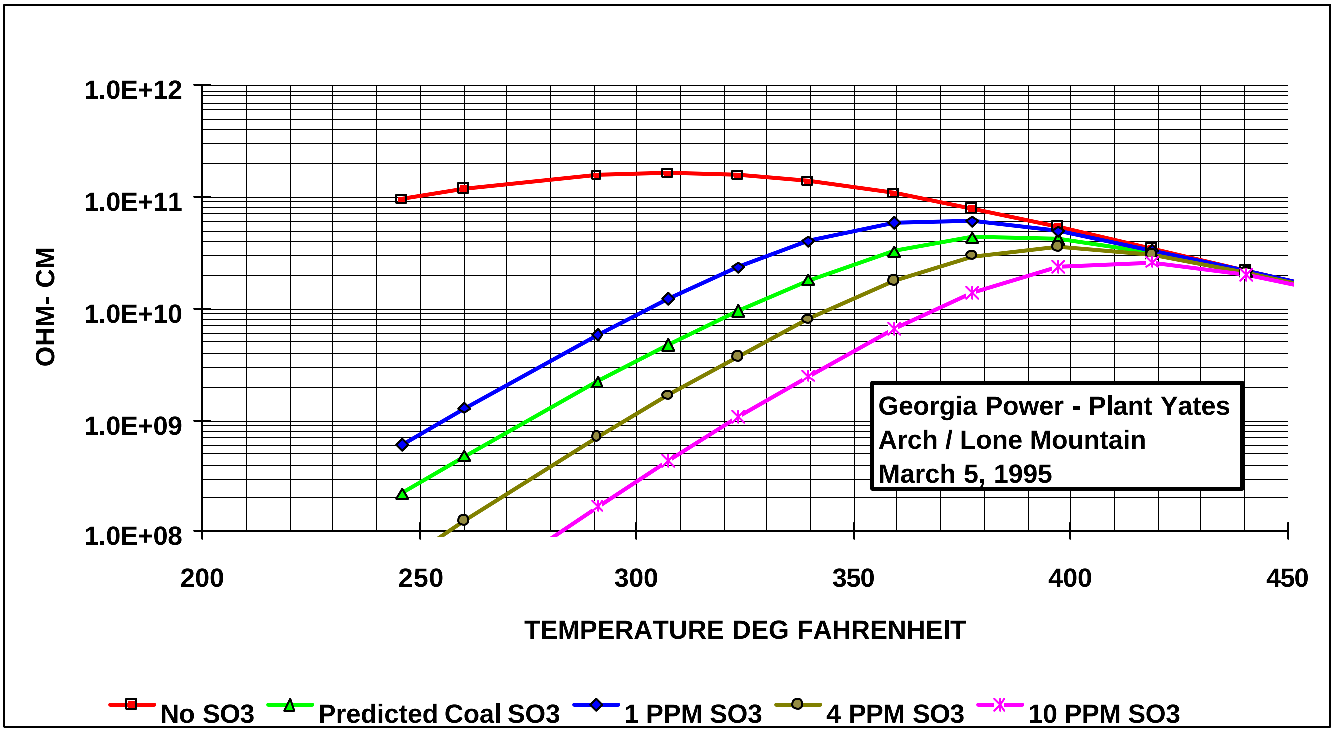

Figure 2. Ash Resistivity, Arch/Lone Mountain Coal

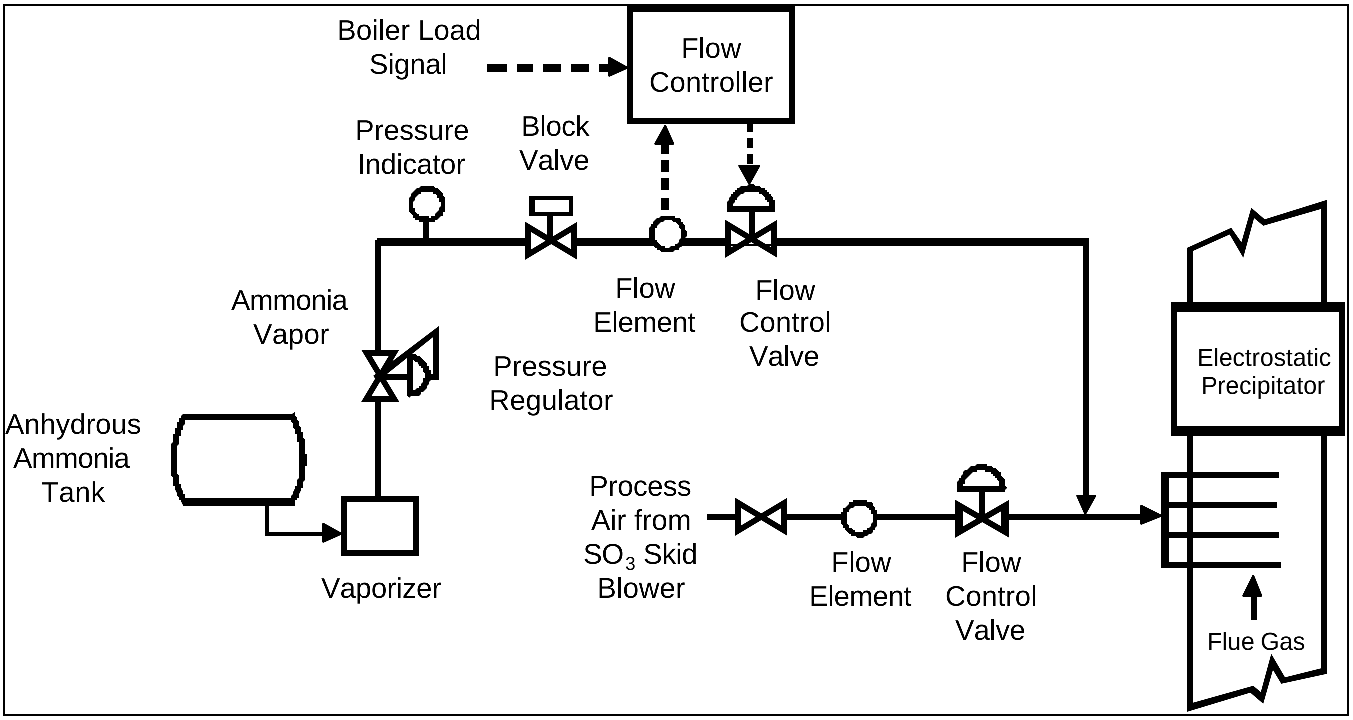

Figure 3. Anhydrous ammonia flue gas conditioning system.

The residence time for the ammonia before the electrostatic precipitator is about 0.75 seconds. The capacity of the ammonia system is 20 lb/hr at a maximum injection rate of 22 ppm.

Control of the ammonia system is provided from the existing Honeywell UDC 9000 operator station on the sulfur trioxide gas generator skid and from the existing supervisory system installed in the boiler control room. Figure 4 is a photo of the ammonia/air distributor.

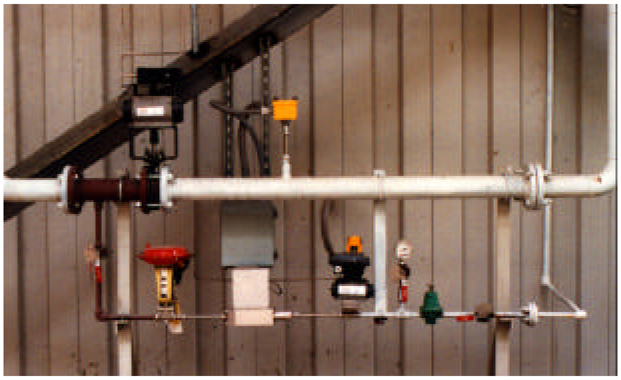

Figure 4. Ammonia/Air Distributor

Plant Yates elected to lease a small 1000 gallon anhydrous ammonia storage tank to minimize OSHA reporting requirements for storage of hazardous substances. The tank provides storage for two to three months at the typical operating rate. The disadvantage of the small tank is that the delivered price of ammonia is about $520/ton, or almost twice as expensive per ton as a complete truckload.

No additional enclosures were required for the upgrade. Equipment and installation costs for the upgrade were less than $100,000. Traditional stand-alone ammonia FGC systems typically cost about $200,000 for equipment and about $100,000 to install. Equipment installation was completed without an outage.

Control of Dual FGC System

The ratio of ammonia to sulfur trioxide is important. Too much ammonia may cause the following problems.

1. Higher ash resistivity and increased particulate emissions.
2. Unreacted ammonia can escape up the stack (NH_3 slip).
3. Excessive precipitator ash buildup.

Excessive sulfur trioxide concentrations could cause excessive sulfur trioxide slip, possible acid dew point problems, and excessive rapper reentrainment. As a general rule the ammonia treat rate is one half to two thirds of the sulfur trioxide treat rate. The ammonia flow is measured with a mass flow element using a boiler load signal indicative of the precipitator gas volume to control to a desired injection rate in ppm.

Performance with Dual Flue Gas Conditioning

Ammonia was first injected at Plant Yates, Unit 5 in September 1995. Prior to injecting ammonia the opacity at a maximum boiler load of 130 mW averaged 17% with rapper spikes to 42% and maximum six minute averages of 19%. Six minute average opacities during load increase from 60 mW to 130 mW were as high as 24%. The sulfur trioxide injection rate was 12 ppm. Throughout this period Unit 4 was off line so the stack opacity was indicative of Unit 5 performance only.

The ammonia injection rate was initially set at 6 ppm. Within three hours the opacity dropped to an average of 11% with rapper spikes to 23%. The maximum six minute average dropped to 12%. Figures 5 and 6 show the instantaneous full load opacity for the period just before and after starting the ammonia conditioning. Precipitator power immediately dropped about 20% upon starting the ammonia injection as shown in Figure 7.

Over the next few days the ammonia treat rate was reduced in stages to 2 ppm. As the ammonia injection was reduced, the precipitator power increased and opacity reached a minimum of about 10% at a 4 ppm injection rate. At a 2 ppm injection rate opacity was maintained at approximately the same level – see Figure 8. Six minute average opacity during load increase did not exceed 15%. Figure 9 is a chart of the six minute opacity for the two-day period just prior to the start of ammonia conditioning and throughout the optimization. No changes were made to the rapping sequence or intensity throughout the period of this program.

Plant Yates ponds the precipitator ash. No problems with ammonia odor have been noted to date.

Operating Cost of System

The estimated yearly operating cost of the ammonia conditioning system is about $6000. The ammonia costs

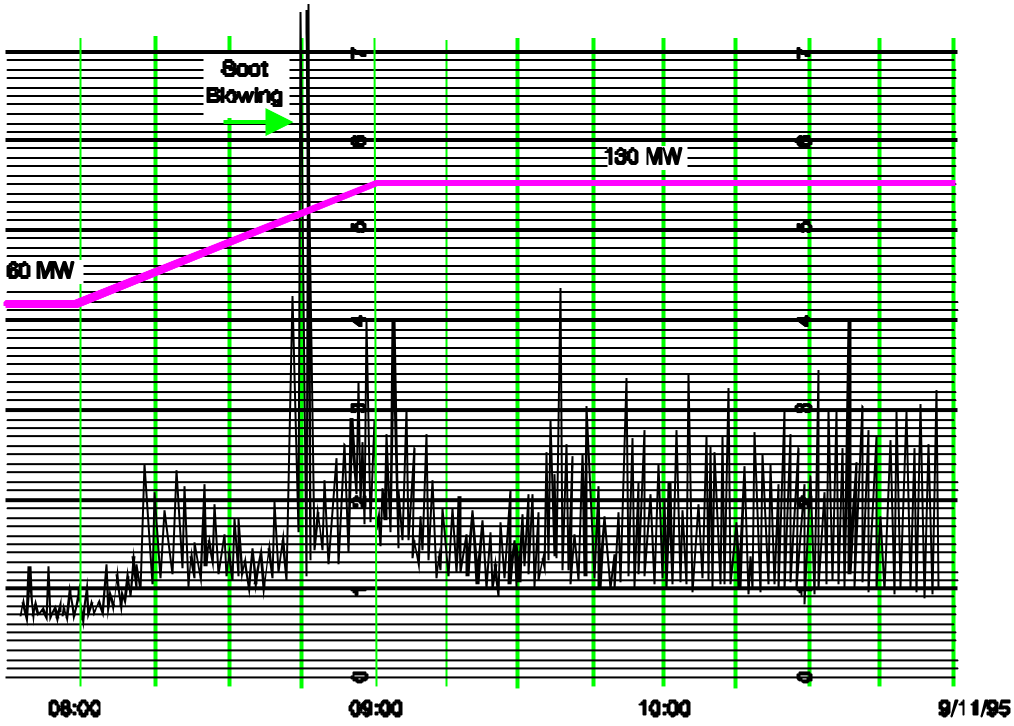

Figure 5. Instantaneous opacity prior to ammonia injection. SO_3 injection rate 12 ppm. (Simulated from actual opacity chart data.)

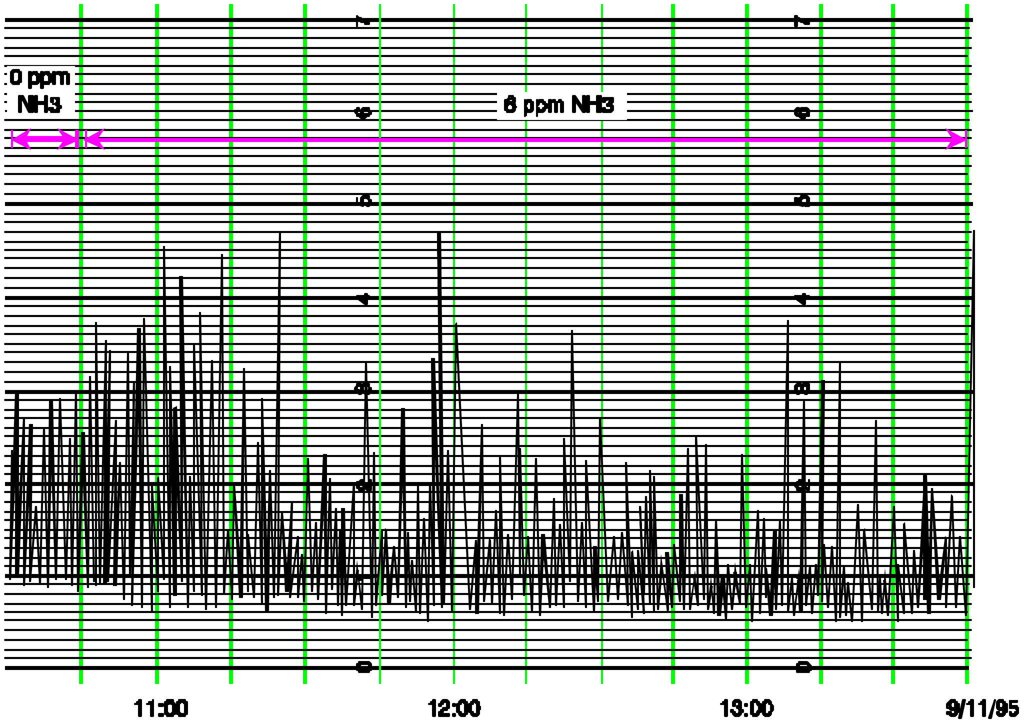

Figure 6. Instantaneous opacity start of ammonia injection. NH_3 6 ppm; SO_3 12 ppm. Boiler load 130 MW. (Simulated from actual opacity chart data.)

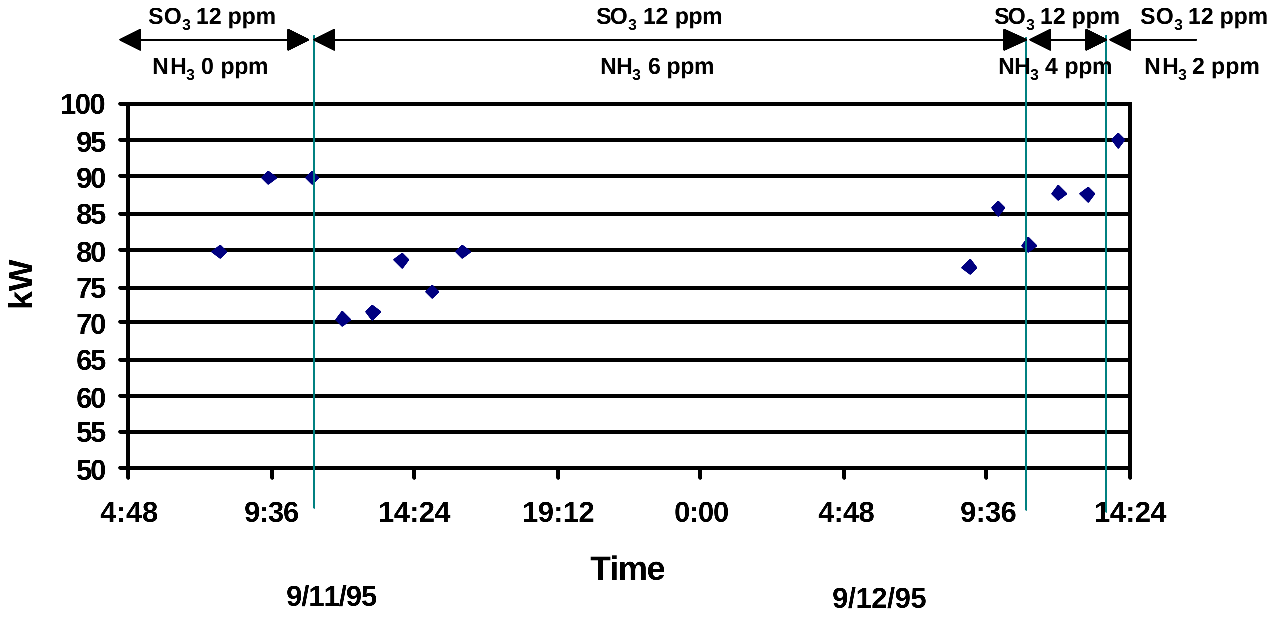

Figure 7. Precipitator Power

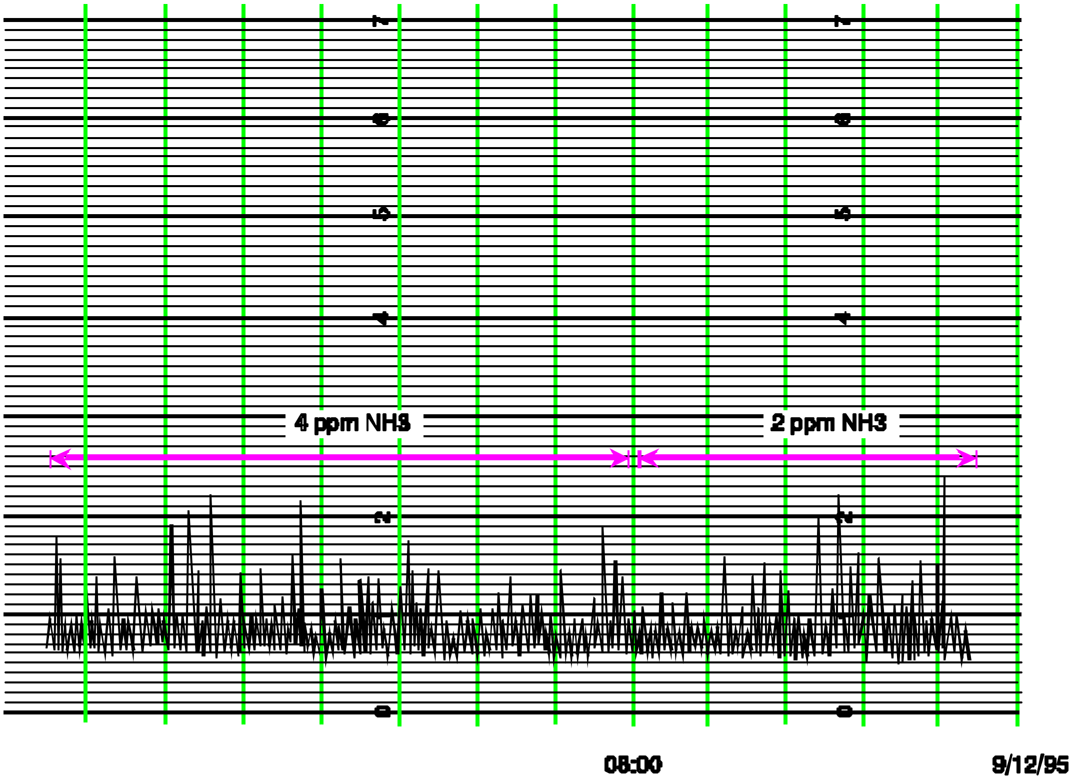

Figure 8. Instantaneous opacity; optimization of ammonia treat rate. Boiler load 130 MW. (Simulated from actual opacity chart data.)

about $520/ton delivered to the site. At the normal treat rate of 2 ppm the ammonia tank is filled every two to three months during peak load periods. Figure 10 illustrates the operating costs for the dual conditioning system vs. treat rate.

Conclusions

1. The dual conditioning system enables the plant to comply with opacity regulations over a wider range of coals. This is probably also true for particulate performance but to date testing has not been performed to verify this.
2. The ammonia system as supplied to Plant Yates Unit 5 is much less expensive than conventional 'stand alone' systems. Integration of the ammonia conditioning equipment with the sulfur trioxide system reduced equipment and installation costs, and simplifies operation of the equipment.
3. A low ammonia treat rate of 2 ppm was adequate to maintain opacity with the West Virginia Mingo Logan coal.
4. Opacity spikes due to rapping were significantly reduced with dual conditioning.
5. Ammonia compounds in the ash have not required any special handling or caused disposal problems at Plant Yates.

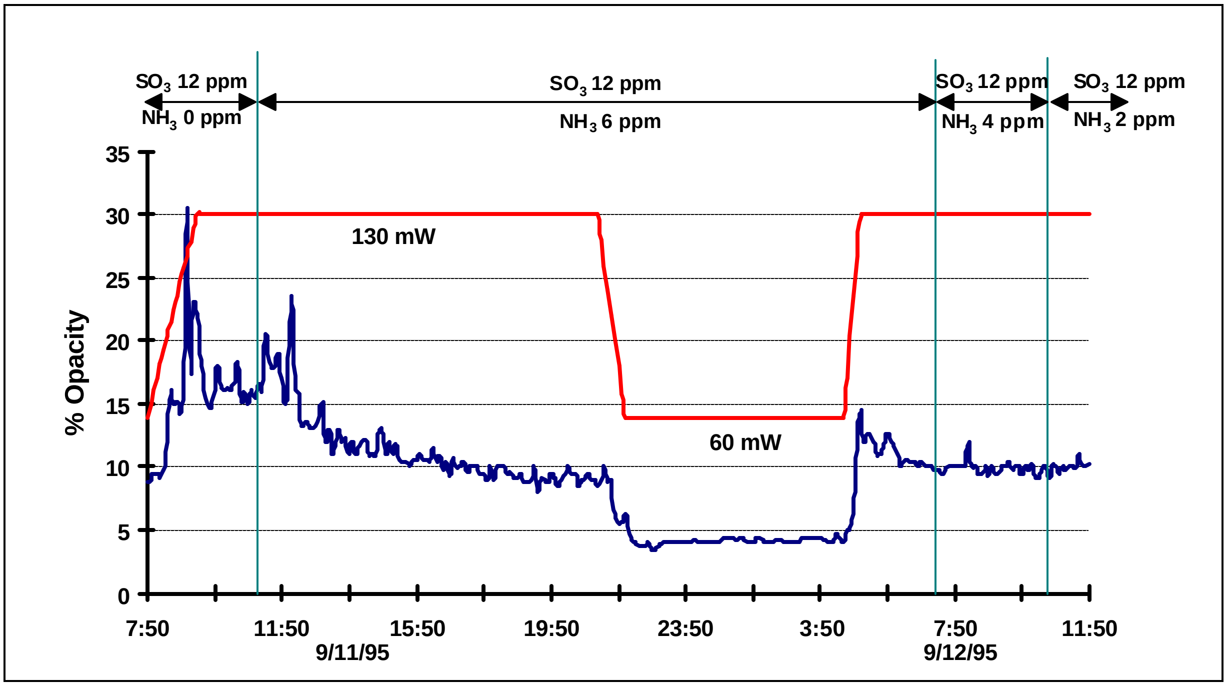

Figure 9. Six minute average opacity.

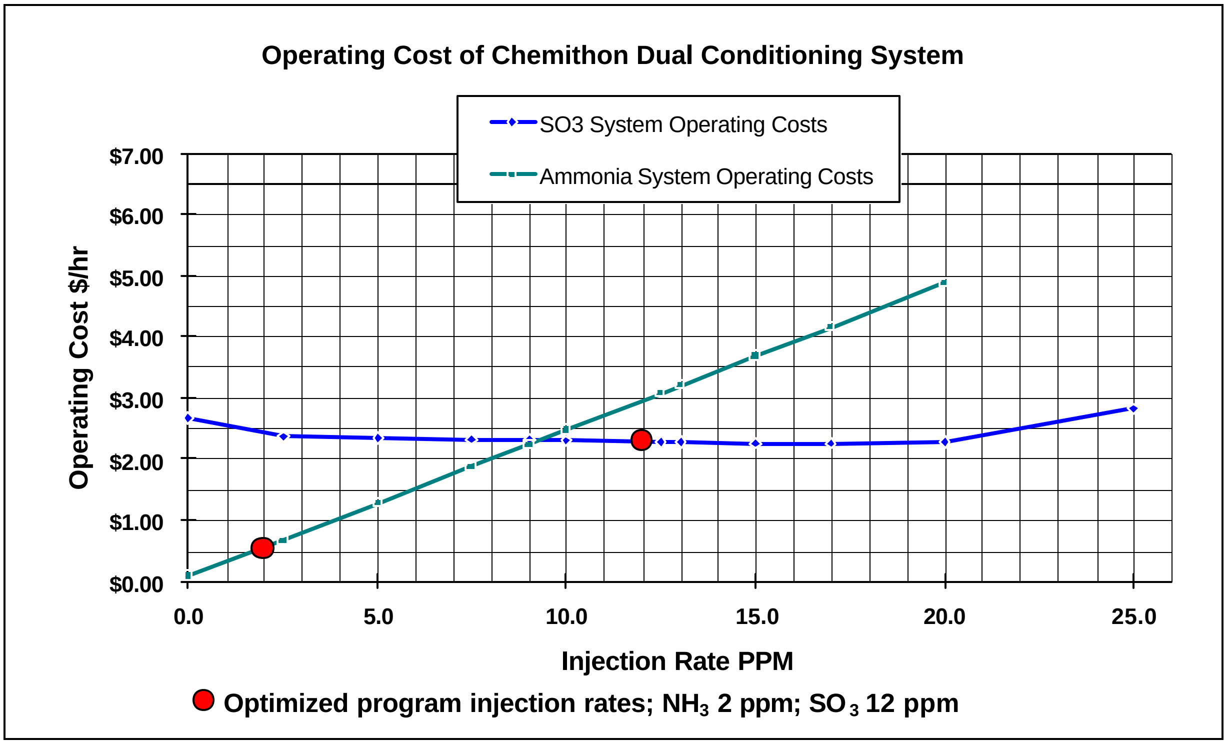

Figure 10. Operating cost of dual conditioning system at Plant Yates, Unit 5.

References

1. H.J. White. Industrial Electrostatic Precipitation. Addison Wesley Publishing Company, September 1962.

2. William Hankins, Ray George. Cost Efficient Flue Gas Conditioning System. Presented at American Power Chicago April 1993.

3. R.B. Spafford, E.B. Dismukes, and H.K. Dillon. Analysis of Thermal Decomposition Products of Flue Gas Conditioning Agents. August 1979. EPA Report EPA-600/7-79-179

4. Harold G. Fletcher. Detroit Edison Company. Coal Selection and Dual Flue Gas Conditioning to Aid in Meeting Air Pollution Control Regulations. APCA Detroit 6/85.

5. H.V. Krigmont, E.L. Coe. Experience with Dual Conditioning Flue Gas Conditioning of Electrostatic Precipitators. 8th Symposium on the Transfer and Utilization of Particulate Control Technology. March 1990, San Diego California