

Advanced Flue Gas Conditioning as a Retrofit Upgrade to Enhance PM Collection from Coal-Fired Electric Utility Boilers

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ABSTRACT

The U.S. Department of Energy and ADA Environmental Solutions are engaged in a project to develop commercial flue gas conditioning additives. The objective is to develop conditioning agents that can help improve particulate control performance of smaller or under-sized electrostatic precipitators on utility coal-fired boilers. The new chemicals will be used to control both the electrical resistivity and the adhesion or cohesivity of the fly ash. There is a need to provide cost-effective and safer alternatives to traditional flue gas conditioning with SO₃ and ammonia.

During this reporting quarter, two cohesivity-specific additive formulations, ADA-44C and ADA-51, were evaluated in a full-scale trial at the American Electric Power Conesville plant. Ammonia conditioning was also evaluated for comparison. ADA-51 and ammonia conditioning significantly reduced rapping and non-rapped particulate re-entrainment based on stack opacity monitor data. Based on the successful tests to date, ADA-51 will be evaluated in a long-term test.

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INTRODUCTION

The Department of Energy National Energy Technology Laboratory (DOE NETL) and ADA Environmental Solutions (ADA-ES) are collaborating on a project to develop advanced commercial flue gas conditioning additives. This project is one of a number of technology development efforts by NETL focused on a goal of achieving particulate emissions as low as 0.01 lbs/mmbtu and control device efficiency of 99.99% should this prove necessary to meet upcoming regulations. The objective of this project is to develop advanced commercial flue gas conditioning additives that can help improve fine particulate control performance of electrostatic precipitators (ESP) on utility coal-fired boilers. Improvements in performance of existing ESPs may be necessary in coming years to meet a variety of new air pollution regulations including fine-particle (PM 2.5) and particulate air toxics. Secondary objectives related to commercialization of the technology include improving in-duct liquid delivery systems, characterizing conditioned fly ash for disposal or utilization, and development of accurate capital and operating costs.

The objective of this program is to develop a family of cohesivity modifying flue gas conditioning agents that can be commercialized to provide utilities with a cost-effective means of complying with particulate emission and opacity regulations. Improving the cohesivity and agglomeration of fly ash particles is a proven means of increasing the collection efficiency of an ESP. Optimizing these properties in combination with control of electrical resistivity is vital to the overall collection efficiency of ESPs, and flue gas conditioning may provide the most cost effective means to meet existing particulate emission standards and upcoming standards for fine particulate emissions.

This new class of additives is needed because currently available agglomerating aids on the market require the storage and handling of large quantities of ammonia, which under recent legislation has been classified as extremely hazardous and necessitates extensive risk assessment and emergency response plans. There are also operating conditions and coals where the ammonia-based technologies are not effective and treated ash may be unusable for recycle applications or difficult to dispose due to ammonia vapor off-gas.

This quarterly report covers technical work undertaken on the project from October through December 2002. During this period work was underway on Task 5, *Conduct Demonstrations to Confirm Performance for Different Coals and Configuration*. Results from the on-going trial at AEP Conesville are updated. Further testing will be conducted at this site in early 2003.

EXPERIMENTAL

AEP Conesville: Process

AEP owns and operates Conesville Station located in Conesville Ohio. Conesville has 6 coal-fired units combining for 2080 MW in power generation. Table 1 summarizes general process information for Unit 3, which will be used for testing the additives. Unit 3 is a front-fired PC boiler rated at 165 MW. The coal fired is a medium-sulfur eastern bituminous.

The primary particulate control equipment used for Unit 3 is a UOP cold-side ESP. The ESP layout is four mechanical fields deep with a total of 96 collection plates. There are 116 gas passes with standard 9" plate spacing. Plate depth is 6 ft. for Field 1 and 9 ft. for Fields 2 through 4. Specific collection area (SCA) is 306 ft²/acfm. Discharge electrode is a conventional weighted stainless steel wire. A total of 5104 wires are the design condition; 342 wires have been removed. There are 16 high voltage wire rappers and 42 plate rappers per field. There are sixteen (16) T/R sets total, with four sets per mechanical field. T/R set ratings are 600 mA secondary current (Field 1) and 1000 mA for Fields 2 – 4. AVC controls are by Forry.

Ash disposal from Unit 3 ESP is a dry pull from hoppers to a Hydroveyor. It is then slurried wet to an on-site disposal pond combined with ash from the other units at the plant. There are a total of eight ash hoppers laid out with a front row collecting from Fields 1 and 2 and a back row from Fields 3 and 4. Ash samples can therefore be collected from either Field 1 & 2 or Fields 3 & 4 or by a composite combination of front and back hoppers. Table 1 is a process summary for Conesville #3.

Table 1: Process Summary, Conesville Unit 3

PARAMETER IDENTIFICATION	DESCRIPTION
Boiler	Riley Stoker, Pulverized, dry bottom, natural gas backup
Coal (typical, 2002)	Eastern Bituminous
Heating Value (Btu/lb)	12,700
Moisture (%)	7.0
Sulfur (%)	2.1
Ash (%)	8.0
SO ₂ (lbs/mmbtu)	3.4
Particulate Control Device	
Type	Cold-Side ESP
Manufacturer	UOP
Design	Weighted Wire
Specific Collection Area (ft ² /1000acfm)	306
Mechanical Fields	4 fields deep x 4 sections each (8 lanes)
T/R layout	One T/R per section, 4 per field.
Flue Gas Conditioning	None
ESP Inlet Temperature, °F	305

Injection System

An ADA-ES flue gas conditioning system was installed on Conesville Unit 3 during summer, 2002 in preparation for this test program¹. With this system, liquid cohesivity additives are injected as dilute, finely atomized spray into both sides of the divided duct upstream of the electrostatic precipitator. The spray droplets flash evaporate in the duct, leaving a finely divided particulate that co-precipitates onto the ESP collection plates. Aqueous ammonia/ammonium hydroxide solution evaporates to vapor-phase ammonia and/or react with SO₂ and SO₃ in the flue gas to form ammonium sulfate compounds.

The injection location is 50 feet (15.2 m) upstream of the precipitator with a single 90-degree bend and one set of turning vanes (Figure 1). A total of 4 deposition probes are installed 24 feet (7.3 m) downstream from the injection lances and just prior to the 90-degree bend and turning vanes. Total residence time from injection to ESP inlet cone is estimated to be 0.3 to 0.5 seconds.

The injection system was installed for temporary service for the duration of the test program. Access to the injection lance deck is by temporary scaffold. Chemical delivery lines are flexible, high-pressure chemical hose. The liquid delivery was heat traced to allow operation during freezing temperatures.

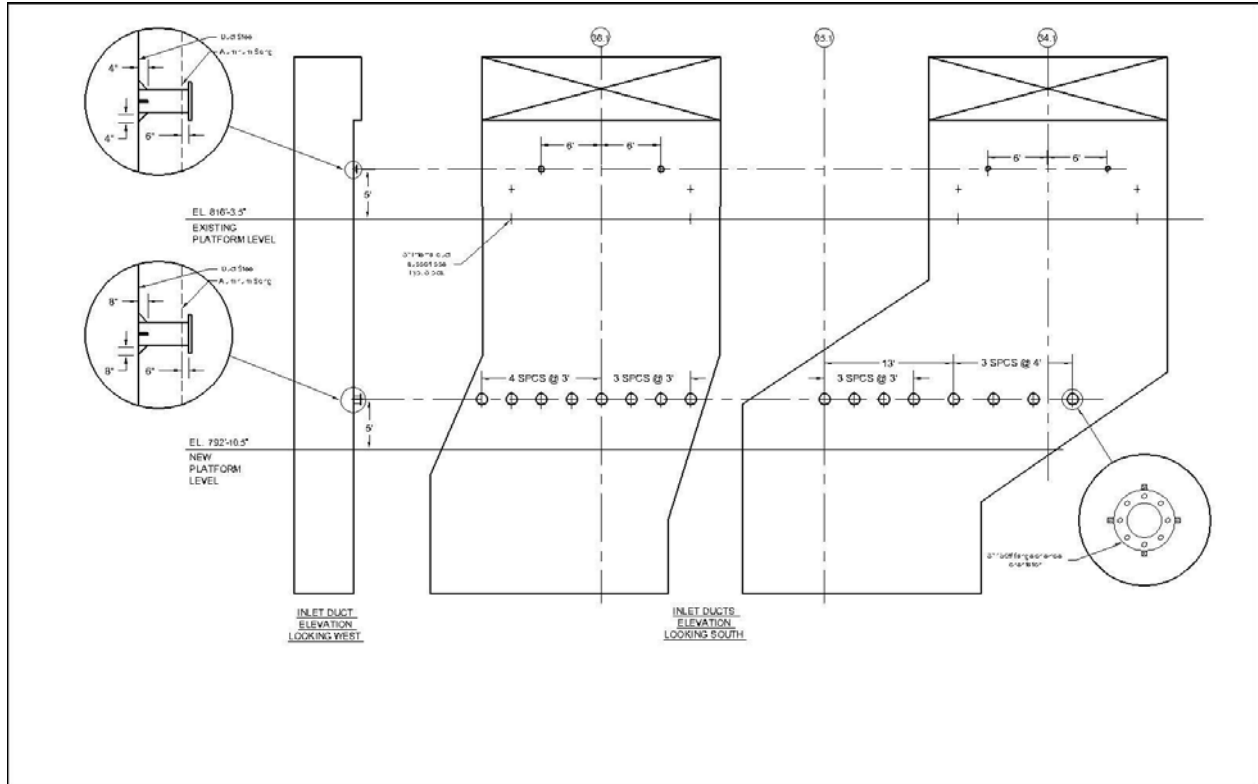


Figure 1: Injection and Deposition Port Layout

Preliminary Additive Test

In the preliminary tests, two proprietary ADA-ES additives and ammonia were evaluated for 8-hour test periods daily, then shut down overnight. ESP electrical data, stack opacity, ash handling, chemical injection equipment, and in-situ deposition probes were all monitored closely to ensure that the chemical conditioning was not detrimental to unit operation. Chemical was injected initially at a low rate and then progressively raised to the expected rate for full conditioning effect.

Long-Term Additive Test

One of the two proprietary additives (ADA-51) was selected for longer-term evaluation. Ammonia was also tested in order to compare results with a known conditioner. The long-term test will be extended and modified to include additional measurements of particulate emissions and ESP inlet particle size and particulate loading. Final results from the long-term are pending. Results in this report include a two-week trial with aqueous ammonia.

RESULTS AND DISCUSSION

Conesville Preliminary Test

The flue gas conditioning trial at AEP Conesville Power Station Unit 3 is aimed at increasing the cohesivity of the fly ash collected by the ESP through the use of chemical additives. Increased cohesivity is expected to improve opacity and to reduce overall particulate emissions. The problems with opacity are most severe during load changes and appear to be directly related to particulate re-entrainment. Unit 3 ash has a high-unburned carbon content in the fly ash that contributes to a low ash tensile strength. Increased cohesivity will produce a more stable ash layer on the ESP plates and in turn, reduce rapping re-entrainment and baseline opacity.

Preliminary test were performed over a two-week period in September and October 2002. Three different flue gas conditioning agents were tested during this period. Table 2 summarizes the observed effect of the three conditioning agents when injected at the indicated feed rates.

Table 2: Summary of Preliminary Results

Additive	Conditioning Rate lbs/ton fuel (Kg/M Ton)	Opacity (%)	Rapping Re-entrainment	Product Handling	Ash & Handling	ESP Electrical Effects	Deposition Probes
ADA-44C	0.2 – 0.9 (0.1 – 0.4)	No significant effect	Minor reduction in opacity spiking	Viscous, required dilution to pump	No problems reported	None observed	Sticky film on probes at high rate
ADA-51	0.3 – 1.6 (0.1 – 0.6)	Baseline opacity reduced	Opacity spiking suppressed	Satisfactory	Normal	None observed	Clean
Aqueous Ammonia	0.8 - 1.5 (0.3 - 0.6)	Baseline opacity reduced 3-5%	Opacity spiking suppressed	Satisfactory	Normal	Power suppression front fields (space charge)	Minor buildup on center probes: ammonium sulfate?

ADA-44C

The first additive injected was ADA-44C, a high molecular weight, water soluble and temperature stable polymer. This material had previously been used in a combination blend with resistivity modifier (ADA-43). The concentrated formulation of ADA-44C contained 40% by weight solids and proved viscous and difficult to pump as received. A 50% dilution with water improved the flowability. Although the as-received liquid polymer was difficult to handle, either polymer molecular weight or solids content could be adjusted as necessary for a production blend. While injecting ADA-44C at the highest rate during preliminary testing, a thin, tenacious coating began to form on the deposition probes. Injection of ADA-44C was discontinued due to the handling difficulties and the evidence of deposition formation at the higher injection rate. Performance results were inconclusive at the rates tested.

ADA-51

ADA-51, a proprietary blended lignin polymer, was injected at rates between 2gph and 12gph. At the higher injection rates (8 to 12 gph), decreases in rapping re-entrainment and baseline opacity were observed within 1 to 2 hours from startup. ADA-51 was easy to handle and produced no deposition, ash handling problems, or adverse ESP effects. Figure 2 below shows the effects of ADA-51 on opacity observed during the preliminary testing. Data plotted is hourly average.

Ammonia

Aqueous ammonia was injected at rates between 8 gph at low load (<100 MW) and 15 gph at high load (>160MW). This corresponds to approximately 20 ppmv vapor ammonia in the flue gas at the ESP inlet, assuming that all aqueous ammonia was vaporized and available for reaction with SO₃. However, the effective concentration was probably lower than this because conversion of aqueous ammonia/ammonium hydroxide to vapor-phase NH₃ and the distribution of the vapor ammonia in the flue gas were likely not ideal with an aqueous feed system. The aqueous ammonia feed rate was adjusted with unit load in order to match the amount of SO₃ in the flue gas. Aqueous ammonia was easy to handle, had no effect on ash handling, and produced minor, flaky deposition on the deposition probes. There was a noticeable decrease in front field power of the ESP likely due to space charge effects.

Long-Term

Ammonia

Aqueous ammonia was injected continuously for several days. Six minute average data from this test is shown in Figure 3. There was a noticeable decrease in both baseline opacity and rapping-induced opacity spikes. At full load, the opacity was reduced from 10 – 12% pre-test to 8% with conditioning in less than 3 hours. After about 24 hours, with a fully conditioned ESP, the opacity was 2 – 5% with almost no opacity spiking at all load conditions. When the ammonia injection is discontinued, there is an immediate increase in baseline opacity and in opacity spiking, although the overall opacity is still lower than pre-test. Note that the six-minute average opacity data presented in Figure 3 does not show the magnitude of instantaneous opacity. This test indicates the significant potential of cohesivity conditioning to reduce particulate emissions and control re-entrainment for Conesville #3.

ADA-51

This test began in late October but was discontinued at the request of the plant due to opacity problems. It was later determined that there was a problem with the opacity monitor data and not an actual opacity problem. Due to the short period of testing that was completed and the lack of reliable opacity data for the ADA-51 long term test, no conclusions can be made about the long term effectiveness of ADA-51. Preliminary testing data indicates that ADA-51 has reduced baseline opacity and rapping spikes; however, long term testing is required to evaluate overall performance.

Testing performed to date has used opacity as an indicator of the particulate reduction in the flue gas leaving the ESP. The use of opacity measurements serves as an approximation for the mass of particulate in the stack gas. An observed decrease in opacity suggests that there is a decrease in particulate; however, particulate testing is required to verify a reduction in particulate and to quantify emission rate. A final test series with inlet/outlet particulate testing is scheduled for January 2003.

Injection System

One of the keys to any successful in-duct liquid chemical conditioning is atomizer spray performance. A secondary objective of this project and of the on-going trial at AEP Conesville is the development and testing of spray atomizers to facilitate chemical injection by liquid spray. The injection lances employed in the ADA-ES injection system at Conesville are a novel design with a single, efficient dual-fluid spray nozzle in a cross flow orientation, as previously described¹. In this design, liquid flow rate is controlled at 6 gph (23 lph) or less per nozzle. Air-to-Liquid (ALR) ratio is increased to achieve ultrafine spray atomization. A high ALR can be economically achieved due to the low liquid volume. Independent spray tests with this injection lance and atomizer have confirmed that the maximum droplet size produced is less than 27 microns diameter and that the Sauter Mean Diameter (SMD) is reliably less than 17 microns. These small atomized droplets will rapidly evaporate the carrier water and will remain entrained rather than depositing on internal duct structures.

For this trial, the injection lances were retrofitted with an outer shield-air sheath. Low pressure shield air around the lance tube is employed to prevent buildup of ash or wet deposition on the nozzle tips. With the addition of shield air, the lances have been utilized for periods of weeks without requiring cleaning in the high particulate concentration of the inlet duct. Deposition probes located downstream from the injection point have remained clean during extended injection tests, indicating excellent spray atomization. This is a significant milestone in development of an efficient, compact spray lance for chemical injection.

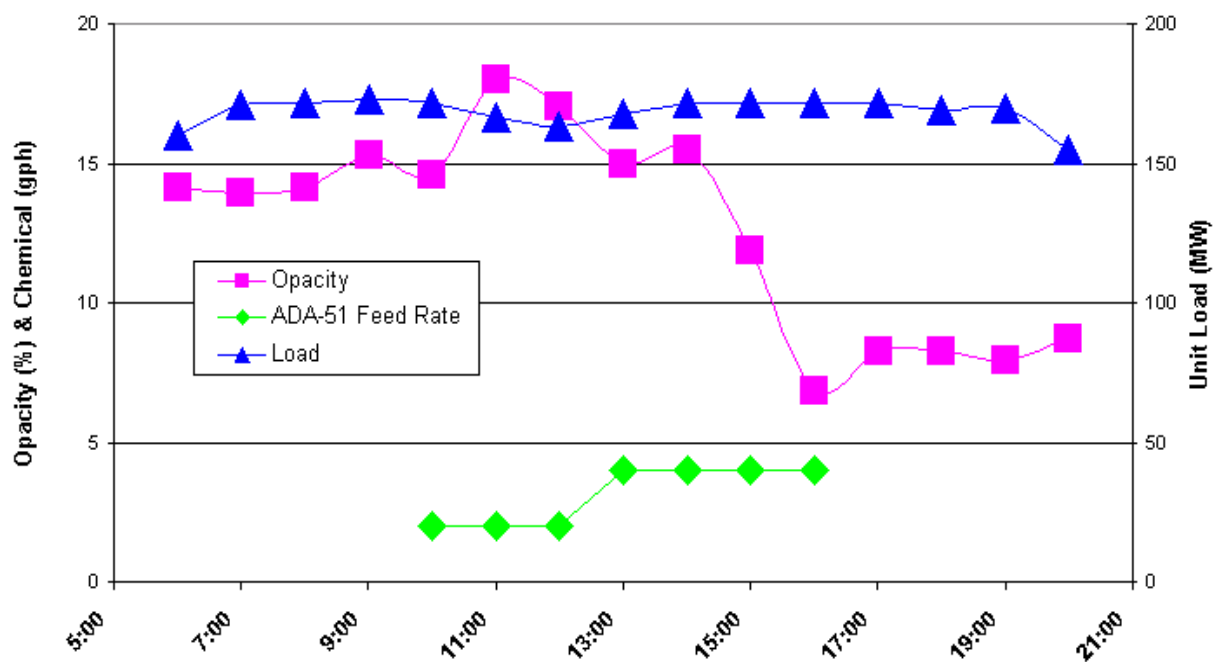


Figure 2: Example of Opacity Response with ADA-51

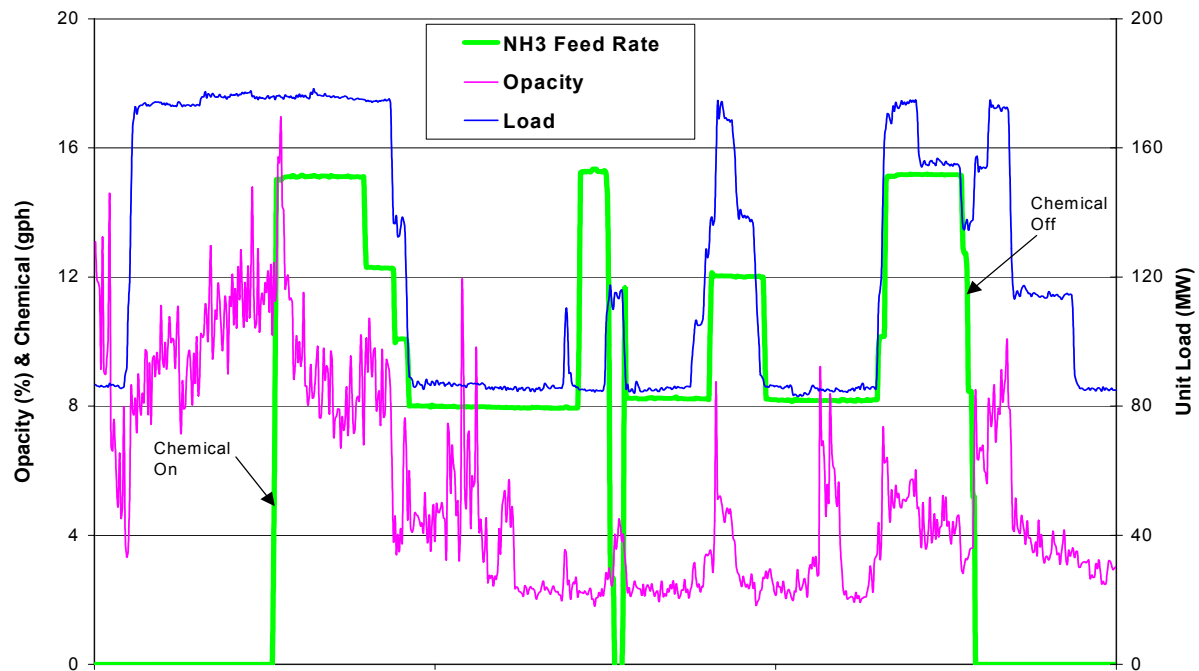


Figure 3: Ammonia Conditioning

CONCLUSION

A test of long-term conditioning with ADA-51 will be completed within the next reporting period. Data to date confirm that cohesivity conditioning has significantly reduce rapping re-entrainment and lowered baseline (non-rapping) opacity by 4 – 5% at full load operation. Optimization of flue gas conditioning through load-following operation and coordination with ESP plate rapping schedules and programs offers further potential for particulate emission reduction.

The main emphasis of this DOE-sponsored project has been to develop cohesivity additives, first by laboratory screening and then in specific full-scale trials at several utility power plants. A final phase of the project will be to extrapolate the full-scale results to other ESP configurations and collection areas in order to assess the performance in a broader, industry-wide context. Results from the AEP Conesville long-term trial with ADA-51 will be used to model the ESP performance with a proven ESP model.

REFERENCES

1. “Advanced Flue Gas Conditioning as a Retrofit Upgrade to Enhance PM Collection from Coal-fired Electric Utility Boilers”, Quarterly Technical Reports, Reporting Periods: Feb. – March 2000, April – June 2000, July – Sept. 2001, Oct. – Dec. 2001, Jan. – March 2002, April – June 2002. DOE NETL Contract No. DE-FC26-00NT40755.

LIST OF ACRONYMS AND ABBREVIATIONS

acfm – Actual Cubic Feet Per Minute

AEP – American Electric Power Company

ALR – Air to Liquid Mass Ratio (spray parameter)

AVC – Automatic Voltage Control

DOE – U.S. Department of Energy

ESP – Electrostatic Precipitator

FGC – Flue gas conditioning for particulate control

ft² – Square Feet

gph – Gallons Per Hour

LOI – Loss on Ignition

lph – Liters Per Hour

mA – Milliamps

MW – Mega Watts

NETL – National Energy Technology Laboratory

NH₃ – Ammonia

PC – Pulverized Coal

ppmv – Parts-Per-Million by Volume

SCA – Specific Collection Area

SMD – Sauter Mean Diameter (mean droplet size, surface)

SO₂ – Sulfur Dioxide

SO₃ – Sulfur Trioxide