**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 have begun 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 flyash. There is a need to provide cost-effective and safer alternatives to traditional flue gas conditioning with SO_3 and ammonia. During the second reporting quarter for this project, design and development is continuing on an electrostatic tensiometer to measure cohesion of flyash layers. A dedicated test fixture to automate flyash electrical resistivity testing is also underway. Ancillary instrumentation to control gas humidification within these test fixtures is also under construction.

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INTRODUCTION

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 flyash particles is a proven means of increasing the collection efficiency of an electrostatic precipitator (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 in today's deregulated utility market for plants to meet DOE's goals of 0.01 lb/Mbtu and 99.99% collection efficiency for particles within the size range of 0.1 to 10 microns.

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 April 1, 2000 through June 30, 2000. During this period work was underway on Task 1, *Upgrade to Additives Test Fixture*. Under Task 1, design and construction of a new flyash resistivity furnace was continued. Design and construction of an oven-mounted electrostatic tensiometer test fixture was also begun. Design and construction of a separate humidity control and measurement system was also underway. This system will be shared by the resistivity furnace and the electrostatic tensiometer. When complete, this instrumentation will allow routine testing of the most critical parameters for the cohesivity additives.

Upgrades to the ADA-ES Additives Spray Chamber were also continued. This facility is used to chemically condition flyash in the laboratory at dosing rates and within an environment that simulates actual flue gas conditioning at full-scale. The current upgrade work is designed to correct several operational deficiencies in ADA-ES' existing spray chamber and it will allow quantitative conditioning with dry solids such as powder polymers.

EXPERIMENTAL

Additives Spray Chamber

A key requirement of this project is a reliable laboratory method to condition flyash with chemical additives. The chemical must be introduced in a way that quantitatively simulates actual conditions in flue gas ducts. Temperature, spray droplet size, chemical concentration, flyash ash concentration, and chemical residence time in the gas stream must all be realistically simulated.

ADA-ES has an existing Additives Spray Chamber that has been used for flue gas conditioning research and development for the past several years. It is also currently used to conduct flyash resistivity tests of conditioned flyash. Experience with this equipment with numerous flyash types has shown that it is possible to reliably apply comparative results between flue gas conditioners to full-scale conditions. However, there are a number of modifications that are needed to the existing instrument to make it suitable for use on this project.

Decoupling Flyash Feed from Process

The flyash feed system of the existing Additive Spray Chamber consists of a conventional rotary screw feeder (Accu-Rate Model 3) that discharges directly into a side gas stream just upstream of the spray chamber. Figure 1 shows the original arrangement. The gas static pressure at the screw feeder input is negative and therefore it is necessary to seal the entire screw feeder hopper to minimize in-leakage of cool, dry air. In practice this is only partially successful; there is always some in-leakage. As the pressure drop across the downstream filter bag increases with particulate buildup during a typical test, this static pressure becomes even more negative. For very loose, non-cohesive ashes the ash can be sucked from the hopper and past the screws. This is undesirable because it adds excess dilution air and the flyash is delivered in short, concentrated bursts. For more densely packed ashes, leakage past the screws is not a problem, but the ash often bridges over in the hopper, again contributing to inconsistency in material feed rate. For some ashes, bridging occurs even though the Accu-Rate line of screw feeders has an advanced, flexible bladder hopper design to prevent this.

The existing flyash metering system was judged to be inadequate for the upcoming laboratory additive evaluation. For this program, repeatable flyash delivery rate and accurate dosing are critical in order to directly compare many candidate additives at the same conditions. In-leakage must be eliminated or minimized and flyash must be fed at a consistent rate regardless of variation of static pressure. With that in mind, ADA-ES has evaluated a number of alternate options for flyash feed.

The flyash feed will be decoupled from the process stream to eliminate erratic feed rate and dilution of humidified process gas. This will be accomplished by the use of a double isolation valve arrangement. The flyash will feed through two automatic air-actuated rotary valves with an intermediate airlock chamber. The valve actuators will be

controlled by two interlocking, timed relays. The valves will alternately open and close so that a seal of the spray chamber to the outside is always maintained. This arrangement solves the problem of air in-leakage. Timers will be adjusted so that valve frequency is sufficient to empty flyash on a continuous basis. It is anticipated that the isolation valves will be cycled to open and closed at less than 10 second intervals. A typical additive conditioning run requires 90 – 120 minutes, so the time scale of the valve action will be essentially continuous compared to the overall test length.

Conditioning by Dry Powder Injection

A further deficiency in the current Additives Spray Chamber setup is the inability to condition the flyash with dry powders rather than with dilute liquids. Some candidate additive conditioners are difficult to introduce as liquid sprays; in particular, most of the cellulose polymers and several other viscosifiers require careful batch mixing and are soluble to less than 5% by weight in water. The ability to introduce these materials as dry solids, at least at the laboratory phase, significantly broadens the scope of materials that can be considered.

Various feeder options and arrangements are being considered for dry powder conditioning. Further design work and feeder procurement is ongoing. The most promising alternative at this point is a Swiss-made vibratory tray feeder (ARBO) as the primary flyash feeder¹. For dry powder conditioning, a much smaller mechanical screw feeder will be used to introduce the dry powder to the vibratory tray ash feed. The lengthy vibratory tray will then allow the two powders to intimately contact and mix prior to injection, but without mechanical compaction or stirring. For tests with conventional liquid spray injection, the vibratory tray will be used to introduce the flyash.

Figure 1: ADA-ES Additives Spray Chamber

Resistivity Furnace

Flyash resistivity is a fundamental measurement for all laboratory tests on the project. In the next stage of the project, the resistivity tests will be conducted in a special muffle furnace with multiple test cells. By running the resistivity in a separate furnace, the Additives Spray Chamber can be devoted exclusively to sample preparation and conditioning. This arrangement will allow duplicate resistivity tests with the same ash sample. Other flyash lab tests, including ash cohesivity, moisture determination, and porosity will also be conducted off-line with split samples from the filter bag catch. Preliminary design of the new resistivity apparatus, as well as upgrades to the Additives Spray Chamber were commenced during the quarter.

Electrostatic Tensiometer

A review of the available laboratory methods to evaluate flyash cohesivity identified the “electrostatic tensiometer”, developed by Southern Research Institute, as best suited for this project^{2,3}. The electrostatic tensiometer measures tensile strength of a dust layer at the point of mechanical failure under increasing electrostatic stress. The method is conducted in an environmental chamber at temperature and humidity simulating an actual cold-side ESP. It is applicable to loose and uncompacted dusts and is therefore more useful than conventional ring shear powder testers that require compaction and sample preparation. For the purposes of this project it is ideal because it will allow a simple measurement of cohesion at conditions closely resembling a flyash layer on ESP plates. ADA-ES has secured a no-fee license from Southern Research Institute to use the technology on this project.

Design and material procurement was underway for the electrostatic tensiometer. It will be built into a dedicated oven with large, integral view window. A diode laser will be mounted to backlight the samples; this gives a much sharper visual indication of particle blow-off from the bottom electrode. The plate spacing will be set to 5 cm. initially as per the SRI method. A high voltage DC power supply will give electric potential to 60 Kv. This will allow applied field strength over a range of 2 – 8 Kv/cm, covering the range of most existing ESPs with conventional 9” (0.23 m.) plate spacing.

Advanced Analytical Methods

Analysis of additional physical properties of conditioned flyash are helpful to characterize both mechanism and degree of conditioning. For example, various thermal techniques including differential scanning (DSC), differential thermal analysis (DTA), and thermo-gravimetric analysis (TGA) could be extremely useful in several aspects of this project, including:

- Polymer and chemical temperature stability (survivability of additive)
- Identification of temperature-sensitive reactions in flyash samples
- Determination of loss of water of hydration vs. temperature
- Thermal indications of adsorption/desorption

- Moisture determinations

During this quarter a survey of instruments and manufacturers of thermo-gravimetric analyzers was conducted. Based on quoted initial capital cost, anticipated investment in proper measurement technique, and time to competency in this instrument, it was determined that the primary need for thermal analysis could best be met by outside laboratories specializing in TGA.

However, rapid and accurate moisture determination as a function of temperature is a routine method that needs to be completed for all flyash samples immediately after conditioning. For this, a high-temperature infrared moisture-determination balance was purchased. This instrument will handle samples over a temperature range of 20°C to 400°C (750°F), using up to 70 gm. of sample. The stated accuracy is 0.1% of sample wt. with readability of 0.01 gm. Although it is not sensitive enough to detect subtle reaction points and changes in physical state, the moisture-determination balance will give useful data with relatively large flyash samples.

Surface area and porosity characterization of flyash is essential for understanding the physical changes that accompany cohesivity conditioning. Changes in bulk porosity have been identified as perhaps the best indicator. ADA-ES routinely employs helium pycnometry to determine true density and bulk porosity. Beyond this, however, characterization of micro-porous and meso-porous surface area by gas sorption would be useful.

After review of product offerings and anticipated use/benefit for an in-house surface area analyzer, it was decided that the additional capabilities of physio-sorptive determination of surface area and pore size could be best met by commercial laboratories specializing in surface area measurement techniques.

CONCLUSION

Work on the project continued with design and procurement for laboratory tests fixtures. The flyash feed system of ADA-ES' Additives Spray Chamber will be substantially modified in order to eliminate air in-leakage and allow more precise control of flyash feed.

Flyash resistivity will be measured in a new multi-cell furnace with programmable temperature controller. The humidity and volume of air in the resistivity furnace will be controlled by feedback to a relative humidity sensor on the outlet vent.

Design and procurement work continued on the electrostatic tensiometer. This method is based on measuring the point of mechanical failure of a flyash layer subjected to increasing electrical repulsion. The point of mechanical failure is identified as the reference tensile strength. The sample is heated and humidified in an environmental chamber and subjected to an electric field equivalent to that in an actual ESP with industry-standard plate spacing.

Additional in-house analytical test methods were considered in order to better characterize effects of chemical conditioning on flyash physical properties. These included BET surface area and various thermal methods, in particular, thermogravimetric analysis. However, it was determined that outside testing laboratories could more efficiently perform these tests on selected samples. A high-temperature moisture determination balance was acquired. This will measure moisture weight loss as a function of temperature to 400°C (750°F).

REFERENCES:

1. Gravimetric Vibratory Tray Feeder, ARBO Engineering Product Literature, 1996.
2. Pontius, D. and Snyder, T., “Measurement of the Tensile Strength of Uncompacted Dust Aggregates” in Powder Technology, 1991, pg. 159 –162.
3. Method And Apparatus For Measuring The Tensile Strength of Powders; US Patent Number 5,386,731, D. Pontius and T. Snyder assigned to Southern Research Institute, 1995.

LIST OF ACRONYMS AND ABBREVIATIONS

DOE – U.S. Department of Energy

ESP – Electrostatic Precipitator

FGC – Flue gas conditioning for particulate control

PM – Particulate matter

PRB – Powder River Basin coals and resulting flyash

TGA – Thermo-Gravimetric Analysis

V/I – Voltage/current