



Project Summary

Flue Gas Conditioning

S-C. Yung, R. G. Patterson, B. L. Hancock, and S. Calvert

The particle collection efficiency of an electrostatic precipitator (ESP) for coal-fired power-plant flue-gas cleaning depends on the electrical properties of the fly ash, among other things. Flue gas conditioning refers to the addition of chemicals to the flue gas for modification of fly ash properties and/or electrical conditions in the ESP to improve the collection efficiency of ESPs. It is usually used for upgrading existing ESPs.

Many existing chemicals have been used as conditioning agents in power plants or have been studied in the laboratory as potential agents. This report gives results of a survey of available agents and user experience.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Electrostatic precipitators (ESPs) have proved reliable, economic, and effective at controlling particle emissions from coal-fired utility boilers. Sometimes their performance has been unsatisfactory because of: (2) coal composition change; (2) more stringent particle emission regulations; (3) unstable electrical conditions; (4) changes in boiler and associated equipment operating conditions; (5) insufficient collection area; or (6) poor maintenance.

There are several methods for upgrading ESP performance: (1) adding collector plate area to the existing ESP to overcome poor performance; (2) using a wet ESP; (3) increasing or lowering the gas temperature in the ESP; and (4) adding chemicals

to modify the fly ash or the electrical conditions in the ESP.

For older ESPs, flue gas conditioning is often the most cost effective way to upgrade performance. Several chemicals are available or have been proposed as conditioning agents. This report gives results of a survey on available flue gas conditioning agents and user experience.

Flue Gas Conditioning

Flue gas conditioning refers to the addition of chemicals to the flue gas in a coal-fired power plant in order to modify fly ash properties and/or improve electrical conditions in the ESP and thus improve the collection efficiency of ESPs. It is usually used to retrofit existing ESPs whose performance has deteriorated, or which are operating below design efficiency.

Collecting fly ash in an ESP involves the precipitation of the ash followed by its successful removal: first from the collection plates; then from the hoppers. For an ESP of given size and operating under fixed conditions, the collection efficiency of the ESP is affected by: (1) the electric field strength and ion density in the precipitation zone; (2) the adhesive and cohesive properties of the fly ash; and (3) the average particle size and size distribution.

A conditioning agent may affect some or all of these factors. The ash resistivity is important because it can affect both (1) and (2) above.

Conditioning Mechanisms

A conditioning agent may influence the ESP collection efficiency through one or more of the following mechanisms: (1) adsorbing on the surface of fly ash to reduce surface resistivity; (2) adsorbing on the fly ash to change the adhesion and

cohesion properties of the ash; (3) increasing ultrafine particle concentrations for space charge enhancement; (4) increasing the electrical breakdown strength of the flue gas; (5) increasing the mean particle size; and (6) changing the acid dew point in the flue gas.

The effects of these mechanisms on ESP performance are described in Table 1.

Flue Gas Conditioning Agents

Many chemicals have been used as conditioning agents in power plants or have been studied in the laboratory as potential conditioning agents. Table 2 lists these chemicals and their principal conditioning mechanisms.

Sulfur Trioxide

Sulfur trioxide (SO_3) is the most widely used conditioning agent in the U.S. It is a natural component of flue gas from fossil fuel combustion. It is hygroscopic and readily becomes sulfuric acid when water is present. When injected in flue gas it may easily be adsorbed to form a layer of conductive solution on the ash surface, thereby reducing the ash resistivity.

For conditioning, SO_3 is produced by one of the following processes: (1) vaporization of a sulfuric acid solution; (2) vaporization of liquid SO_3 ; (3) vaporization of liquid SO_2 and oxidation to SO_3 over a vanadium pentoxide catalyst; and (4) burning liquid sulfur in air to produce SO_2 and then oxidation to SO_3 .

Ammonia

Ammonia is a vapor at room conditions, and its critical temperature is 132°C . Above this temperature, ammonia exists as a single phase and cannot boil or condense. Therefore, condensation on the fly ash would not be expected with ammonia above 132°C , although adsorption might.

Because of the high volatility of ammonia, it is injected in the vapor form under its own vapor pressure. In Australia, ammonia is also injected in aqueous solution form.

Ammonium Compounds

Conditioning with ammonium compounds offers a more convenient way of injecting ammonia. The commonly used ammonium compounds are sulfamic acid, ammonium sulfate, and ammonium bisulfate. When injected upstream of the air preheater, these compounds could decompose to ammonia and sulfuric acid and, therefore, may provide a combination

of the effects of ammonia and sulfuric acid conditioning.

Organic Amines

Organic amines have been studied in the laboratory and pilot scale ESPs as possible flue gas conditioning agents. Currently, there are no commercial users. Of all the amines, triethylamine has received the most attention. It is an organic nitrogen compound and is highly soluble in water. It behaves similarly to ammonia, but is a substantially stronger base. The melting and boiling points of triethylamine are -115°C and 90°C , respectively. It decomposes extensively to ammonia, hydrogen cyanide, nitrogen dioxide, and nitric oxide at temperatures above 340°C (650°F).

Dry Alkali

Ash resistivity is indirectly related to the alkali content in the ash, and reduction of ash resistivity by increasing the alkali concentration has been tried. Of the many alkali salts, sodium salts are the most commonly used conditioning agents because of their availability and relatively low cost. The widely used sodium compounds are sodium carbonate and sodium sulfate. Sodium chloride has been tried in the laboratory and found to be effective. However, it is not used because it can lead to corrosion of metal equipment.

The mechanism for sodium conditioning depends on how the sodium is applied. If a sodium compound is injected into the boiler along with coal, it will decompose and the sodium is bound in the ash. The sodium will increase the conductivity and lower the ash resistivity the same way as natural sodium.

If the sodium compound is co-precipitated with the ash, the compound trapped in the space between the particles on the dust layer offers an additional conductive path for charge dissipation.

Alkali earth compounds have also been studied, including dry limestone and magnesite. It is thought that these compounds react with excess sulfuric acid to enhance the space charge effect.

Proprietary Formulations

Most of the proprietary chemicals are ammonium compounds with minor additives, such as surface active agents. Preparations such as this would perform similarly to ammonium compounds.

Miscellaneous Compounds

Several metal oxides, such as iron and vanadium oxides, have been investigated

as possible conditioning agents. Iron and vanadium oxides are claimed to catalyze the reaction of SO_2 to SO_3 and thus increase the quantity of SO_3 present in the flue gas. This claim has not been substantiated in the literature.

Results

Table 3 lists past and present flue gas conditioning users in the U.S. Summaries of user experiences follow.

Sulfur Trioxide

SO_3 conditioning is limited to cold-side ESPs. The most common injection location is between the air preheater and the ESP inlet. The temperature at the point of injection and in the precipitation should be above the sulfuric acid dew point of the gas after addition.

The dosage for SO_3 injection normally is in the range of 5 to 30 ppmv, but can be as high as 70 ppmv. The required dosage will depend on the composition of the ash surface; i.e., if it is acidic, neutral, or basic. If the ash has a large amount of alkaline compounds, a higher dosage of SO_3 is needed because the alkaline compounds will react with, or neutralize, the adsorbed sulfuric acid.

SO_3 conditioning is effective in reducing ash resistivity and improving ESP performance if it is applied properly, but only where high particle resistivity is the limiting factor in ESP performance. For highly resistive ashes, an addition rate of 20 ppmv can lower the resistivity by two orders of magnitude (from about 10^9 to 10^{10} ohm-cm to 10^7 to 10^8 ohm-cm).

There are cases of non-effectiveness where SO_3 conditioning has not been effective for one or more of the following reasons: (1) the conditioner supply malfunctioned; (2) the ESP performance is limited by phenomena other than ash resistivity; (3) the ash resistivity may already be satisfactory; (4) the temperature may be so low that acid condenses at the injection point before the SO_3 is mixed with the flue gas; and (5) the temperature is much higher than the acid dew point.

Even though SO_3 conditioning can improve the particle collection efficiency of the ESP, it can increase the emissions of sulfuric acid mist and particulate sulfate compounds. The emission rate of added SO_3 is higher for acidic ashes and high gas temperatures existing in ESPs.

Due to increased particle collection by the ESP, plume opacity is usually lower with conditioning. However, an "acid plume" could be formed if the SO_3 dosage and gas temperature are too high.

Table. 1. Mechanisms by Which a Conditioning Agent May Affect Precipitability

<i>Effect of Conditioning Agent</i>	<i>Electrical Result</i>	<i>Mechanical Result</i>	<i>Effect on Efficiency^a</i>	<i>Comments</i>
<i>Adsorbs on surface of fly ash and reduces surface resistivity</i>	<i>Increases the magnitude of the precipitation field; Reduces the voltage drop in the dust layer; Delays the onset of back corona; Increases the sparkover voltage</i>		<i>SIE</i>	<i>Useful for high resistivity dusts: Increases charging and precipitation field strength; Reduces electrical adhesion on the wall and thus improves the effectiveness of rapping.</i>
	<i>Reduces the electrical adhesion effect on the wall</i>		<i>IE or DE</i>	<i>Beneficial for high resistivity dusts. If used with low or medium resistivity dusts, further lowering of adhesion forces could lead to reentrainment losses.</i>
<i>Adsorbs on fly ash and changes cohesiveness or "stickiness"</i>		<i>Aids agglomeration and increases mean particle size</i>	<i>IE</i>	<i>Size enhancement may occur independently of resistivity change and thus improve migration velocity.</i>
		<i>Dust layer on wall becomes more cohesive</i>	<i>IE</i>	<i>Larger size fraction also aids removal by rapping; Cohesive dust layer tends to shear off collecting plate with less reentrainment losses.</i>
		<i>Dust layer has stronger adhesion to wall</i>	<i>IE or DE</i>	<i>Stronger adhesion is an advantage for low resistivity dusts; Could be a disadvantage for high resistivity dusts.</i>
<i>Increases particle concentration due to presence of fines (i.e., particulate reaction products)</i>	<i>Reduces ion density (and thus current) due to space charge suppression</i>		<i>IE or DE</i>	<i>The current reduction could reduce charging effectiveness. On the other hand, the lower current density will alleviate field reduction problems caused by the voltage drop through a high resistance dust layer.</i>
	<i>Increases collection field strength due to space charge enhancement</i>		<i>IE</i>	<i>Space charge increases the field strength near the collecting electrode.</i>
	<i>Increases sparkover voltage</i>		<i>IE</i>	<i>A slight increase in sparkover voltage usually results from increased space charge.</i>
<i>Increases electrical breakdown strength of flue gas</i>	<i>Increases the magnitude of the precipitator field; Increases sparkover voltage; Delays onset of back corona</i>		<i>SIE</i>	<i>The breakdown characteristics of flue gases are very sensitive to minor concentrations of electro-negative species and to surface conditions of the dust layer. This can be independent of fly ash resistivity.</i>
<i>Neutralizes acid in flue gas</i>	<i>Decreases acid dew point. This reduces surface "tracking" on high voltage insulators, allowing higher voltages to be applied.</i>		<i>SIE</i>	<i>With some high sulfur coals, the sulfuric acid concentration in the flue gas is so high that the acid dew point may be above the flue gas temperature. This may result in acid condensation on support insulators.</i>

^a*SIE = strong tendency to increase efficiency.*

IE = tendency to increase efficiency.

DE = tendency to decrease efficiency.

Table 2. Flue Gas Conditioning Agents and Mechanisms

Conditioning Agent	Conditioning Mechanisms
SO ₃ (H ₂ SO ₄)	Resistivity modification
NH ₃	Adhesion and cohesion Space charge enhancement
Ammonium Compounds (SO ₂ OH)NH ₃ (sulfamic acid) (NH ₄) ₂ SO ₄ NH ₄ HSO ₄ (NH ₂) ₂ CO (NH ₄) ₂ HPO ₄	Space charge enhancement Resistivity modification
Organic Amines (CH ₃ CH ₂) ₃ N (Triethylamine) (CH ₃) ₃ N (Trimethylamine) (C ₆ H ₁₁)NH ₃ (Cyclohexylamine)	Resistivity modification
Alkali Compounds Na ₂ SO ₄ Na ₂ CO ₃	Resistivity modification
Proprietary Compounds Apollo LPA-30 Apollo LPA-40 Apollo LPA-50 Koppers "K"	Resistivity modification Space charge enhancement

Operating Problems—Interviews of several users of SO₃ conditioning revealed the following operating difficulties: (1) corrosion of injection lines; (2) deactivation of catalysts in the SO₂ to SO₃ converter; and (3) over-conditioning (resistivity lowered too much).

Economics—The estimated capital and operating costs of a SO₃ flue gas conditioning installation as of December 1982 are \$5.15/kW and 0.105 mills/kWh, respectively.

Ammonia

Ammonia is injected either before or after the air preheater in vapor or liquid form. Most of the users inject it downstream of the air preheater to avoid plugging the preheater with deposits of ammonia reaction products.

The ammonia injection dosage is about 15 to 20 ppmv. In most situations, ammonia can improve the ESP performance. However, the way in which ammonia affects the performance of ESPs is not completely understood. It seems that in different applications, it affects ESP performance through different mechanisms. It is not effective with all ashes, and its behavior in each case appears to depend mainly upon the initial ash resistivity, flue gas composition, and temperature.

The ability of ammonia to alter resistivity is not clear. Ammonia-conditioned resistivities can be less than, the same as, or greater than the unconditioned values.

The temperature of the ESP has great effect on resistivity modification by ammonia. Since the critical temperature for ammonia is 132°C, physical adsorption or condensation of ammonia is not expected to occur above this temperature. Therefore, ammonia injection will not change the ash resistivity above this temperature unless it is sorbed as a reaction product as NH₄SO₄.

The improvement in ESP performance when ammonia is injected is more likely due to space charge enhancement and improvement in cohesive force between the ash particles. The injected ammonia reacts with the existing sulfuric acid vapor, forming a fume of fine salt particles of ammonium bisulfate and sulfate. This fume creates a large surface area for collecting electrons. These charge carriers have a lower mobility than electrons, allowing for a more stable corona, higher electrical field strength without breakdown, and higher specific power.

Ammonia is sometimes injected along with SO₃. Sulfuric acid condensation in the presence of ammonium bisulfate and sulfate leads to the adsorption of acid and salts to water on the surface. These surface deposits are viscous and cohesive, which reduces particle reentrainment from the collection plates.

The emissions caused by ammonia injection are minimal. A significant part of the ammonia is reacted with nitrogen oxides to form elemental nitrogen. Re-

action between ammonia and SO₃ also decreases the SO₃ emission.

Operating Problems—Ammonia conditioning could have the following operating and maintenance problems: (1) plugging of injection nozzles; (2) leakage and freezing of injection lines; and (3) dust buildup on discharge electrodes.

Economics—The capital and operating costs of ammonia conditioning, in December 1982 U.S. dollars, are \$0.21/kW and 0.022 mills/kWh, respectively.

Ammonium Compounds

Ammonium compound injection rates are in the range of 0.25 to 1.0 g/kg of coal burned. They are injected in solution form either upstream or downstream of the air preheater. Upstream is preferred because it offers long residence time and high temperature to vaporize or decompose the agent. However, upstream injection could cause plugging of the air preheater.

Since ammonium compounds currently used for conditioning decompose to ammonia and sulfuric acid, they improve the ESP performance through the mechanisms of resistivity modification and space charge effect. They are not as effective as SO₃ in lowering the ash resistivity. Results show that they can lower the ash resistivity by about half an order of magnitude.

The injection of compounds decomposing to ammonia and SO₃ may cause increased sulfate and ammonia emissions. Sulfate emission rates of about 20 and 1,500 µg/m³ were measured in a field study, without and with conditioning, respectively.

Problems—The most common operating problem with ammonium compound conditioning agents has been plugging of the air preheater by deposits of combustion products when the agent is injected upstream of the air preheater.

Economics—There is no information on capital costs for ammonium compound conditioning systems. The operating costs range from 0.024 to 0.052 mills/kWh (December 1982 U.S. dollars).

Organic Amines

Even though triethylamine is less volatile than ammonia, it can be injected in the vapor phase as well as in the solution form. Because it decomposes at high temperature, it is injected downstream of the air preheater.

The mechanism of triethylamine is not fully understood. The most likely mecha-

Table. 3. Past and Present Flue Gas Conditioning Users

<i>Company Name</i>	<i>Plant Name</i>	<i>Boiler No.</i>	<i>PGC Licensor</i>	<i>FGC Agent</i>
Alabama Power Co.	Barry	4	Wahlco	Sulfur trioxide
AEPSCO Appalachian Power	Cabin Creek			
AEPSCO Appalachian Power	Kanawha River			
AEPSCO Columbus & Southern Ohio Electric	Conesville	4		
Arizona Public Service Co.	Four Corners	4	Apollo	LPA-445
Baltimore Gas & Electric	H. A. Wagner	3	Apollo	
Central Illinois Light	Duck Creek		Apollo	
Central Illinois Light	E. D. Edwards	1, 2, 3	Wahlco	Sulfur trioxide
Central Illinois Light	R. S. Wallace	7, 8, 9, 10	Wahlco	Sulfur trioxide
Cincinnati Gas & Electric Co.	W. C. Beckjord	1, 2, 4	Wahlco	Sulfur trioxide
City of Colorado Springs DPU	Martin Drake	1, 5	Research-Cottrell	Sulfur trioxide
Cleveland Electric Illuminating Co.	Ashtabula	5	Wahlco	Sulfur trioxide
Cleveland Electric Illuminating Co.	Avon Lake	9	Wahlco	Sulfur trioxide
Cleveland Electric Illuminating Co.	Eastlake	5	Wahlco	Sulfur trioxide
Cleveland Electric Illuminating Co.	Lake Shore	18	Wahlco	Sulfur trioxide
Colorado-Ute Electric Assoc.	Hayden	1, 2	Apollo	
Commonwealth Edison	Crawford	7, 8	Wahlco	Sulfur trioxide
Commonwealth Edison	Fisk	19	Wahlco	Sulfur trioxide
Commonwealth Edison	Joliet	3, 4, 5, 6	Wahlco	Sulfur trioxide
Commonwealth Edison	Joliet	71, 72, 81, 82		
Commonwealth Edison	Powerton	51, 52	Wahlco	Sulfur trioxide
Commonwealth Edison	Waukegan	15, 16, 17, 8	Wahlco	Sulfur trioxide
Commonwealth Edison	Will County	4	Wahlco	Sulfur trioxide
Commonwealth Edison/Indiana	State Line	1-1, 1-2, 1-3	Wahlco	Sulfur trioxide
Commonwealth Edison/Indiana	State Line	1-4, 1-5, 1-6		
Commonwealth Edison/Indiana	State Line	2-1, 2-2, 2-3, 3, 4		
Consumers Power Co.	B. C. Cobb	1, 2, 3, 4, 5	Wahlco	Sulfur trioxide
Consumers Power Co.	J. C. Weadock	7, 8	Wahlco	Sulfur trioxide
Detroit Edison	Conners Creek	15, 16	Wahlco	Sulfur trioxide
Detroit Edison	Harbor Beach	1	Wahlco	Sulfur trioxide
Detroit Edison	Monroe	1, 2	Wahlco	Sulfur trioxide
Detroit Edison	Pennsalt		UOP	Sulfur trioxide
Detroit Edison	Port Huron	5	Wahlco	Sulfur trioxide
Detroit Edison	Trenton Channel	7, 8, 9A	Wahlco	Sulfur trioxide
Duke Power	Belews Creek	1, 2	Research-Cottrell	Sulfur trioxide
Duke Power	Marshall			
East Kentucky Rural Electric Power Coop.	W. C. Dale	3, 4	Wahlco	Sulfur trioxide
Florida Power	Crystal River	2	Apollo, Nalco	
Georgia Power	Harlee Branch	3, 4	Apollo	
Gulf Power Co.	Scholz			
Iowa Public Service Co.	G. W. Neal	2, 4	Wahlco	Sulfur trioxide
Lansing Board of Water & Electric Light	Erickson	1	Wahlco	Sulfur trioxide
Montana Power Co.	J. E. Corette	1	Apollo	LPA-40
New England Power Co.	Salem Harbour		Nalco	
New England Power Co.	Brayton Point		Nalco	
New Jersey Gas & Electric	Mercer		Apollo	LPA-40
New York State Electric & Gas	Goudey	11, 12	Wahlco	Sulfur trioxide
New York State Electric & Gas	Greenidge	4, 5, 6	Wahlco	Sulfur trioxide
Northern Indiana Public Service Co.	D. H. Mitchell	4, 5, 6, 11	Wahlco	Sulfur trioxide
Northern Indiana Public Service Co.	D. H. Mitchell		Apollo	
Ohio Edison Co.	Edgewater		Dusco	
Ohio Edison Co.	Gorge		Dusco	
Ohio Edison Co.	W. H. Sammis	1, 2, 3, 4, 5, 6, 7	Wahlco	Sulfur trioxide
Ohio Edison Co.	W. H. Sammis		Apollo	
Pacific Power & Light	Bridger			Ammonia
Pacific Power & Light	Centralia	1, 2		

Table 3. (Continued).

<i>Company Name</i>	<i>Plant Name</i>	<i>Boiler No.</i>	<i>PGC Licensor</i>	<i>FGC Agent</i>
Pennsylvania Electric Co.	Front Street	9, 10	Wahlco	Sulfur trioxide
Pennsylvania Electric Co.	Keystone	1, 2		
Pennsylvania Power & Light Co.	Brunner Island	1, 3	Wahlco	Sulfur trioxide
Pennsylvania Power & Light Co.	Montour	1, 2	Wahlco	Sulfur trioxide
Pennsylvania Power & Light Co.	Montour		Apollo	LPA-402A
Pennsylvania Power & Light Co.	Sunbury	3, 4	Wahlco	Sulfur trioxide
Public Service Co. of Colorado	Arapahoe	1, 2, 3, 4	Wahlco	Sulfur trioxide
Public Service Co. of Colorado	Cameo	2		
Public Service Co. of Colorado	Cherokee	1, 2, 3, 4	Lodge-Cottrell	Sulfur trioxide
Public Service Co. of Colorado	Comanche	1, 2		
Public Service Co. of Colorado	Valmont	5	Nalco	
Public Service Electric & Gas, New Jersey	Hudson		Apollo	
Public Service Electric & Gas, New Jersey	Mercer		Apollo	LPA-40
Salt River Project	Hayden	2		
South Carolina Public Service Authority	Jefferies	3, 4	Apollo	LPA-40
Tampa Electric Co.	Big Bend			
Tampa Electric Co.	F. J. Gannon	5, 6	Apollo	LPA-40
Tennessee Valley Authority	Bull Run	1		Ammonia
Tennessee Valley Authority	Gallatin	4		Ammonia
Tennessee Valley Authority	Kingston	5		
Tennessee Valley Authority	Shawnee	10		
Tennessee Valley Authority	Widows Creek "B"	7, 8		Ammonia
TUGCO Dallas Power & Light	Big Brown		Apollo	
TUGCO Dallas Power & Light	Monticello	1, 2	Apollo	
Toledo Edison	Bayshore		Nalco	
UGI Corp. Luzerne Electric	Hunlock Creek		UOP	Sulfur trioxide
Upper Peninsula Generating Corp.	Presque Isle	1, 2, 3, 4, 5, 6	Apollo	Sulfur trioxide
Upper Peninsula Generating Corp.	Presque Isle	1, 2, 3, 4, 5, 6	Wahlco	Sulfur trioxide
Utah Power & Light	Naughton	3	Wahlco	Sulfur trioxide
Virginia Electric & Power	Yorktown		Apollo	
Wisconsin Electric Power Co.	Pleasant Prairie	1, 2	Wahlco	Sulfur trioxide
Wisconsin Power & Light	Columbia	1		

nism is ash resistivity reduction. One pilot plant study showed that resistivity decreased from 3×10^{11} ohm-cm (without conditioning) to 5×10^7 ohm-cm (with a triethylamine dosage of 60 ppm). Another pilot plant study showed similar results. With an injected concentration of 25 ppm of triethylamine, resistivity decreased one to two orders of magnitude in the temperature range of 100°C to 150°C. It is more effective the lower the temperature, the less basic the ash composition, and the greater the concentration of the agent.

Triethylamine has only been studied in the laboratory and in pilot plants. There are no commercial users, so no user experience or economic data are available.

Dry Alkali

Sodium conditioning, unlike with other conditioning agents, is not limited to cold-side ESPs. It can be added to the boiler

along with coal or into the flue gas just ahead of the ESP. It can be applied either in solution or dry powder form. The most important parameter which affects its effectiveness is the mixing of the sodium salt and the fly ash. To be effective, the sodium must be either incorporated into all the ash particles or co-precipitated with the ash on the ESP plates so it yields well-mixed deposits.

When sodium is applied in dry powder form for co-precipitation, there may be difficulties in obtaining well-mixed deposits. Some researchers applied the sodium in solution form and claimed that a uniform coating of sodium salts was obtained on ash particles. When the agent is injected for co-precipitation with the ash, the dosage is 2 to 5 percent of the solids as Na_2O . The co-precipitated sodium compound should have a particle size distribution comparable to that for the ash.

Sodium is effective in reducing the fly ash resistivity if the sodium is mixed well

with the ash. *In situ* resistivity measurements of co-precipitated ash showed the resistivity decreased from 2.1×10^{10} ohm cm (without conditioning) to 3.7×10 ohm-cm (when conditioned with a 1.0 to 1.5 percent concentration of sodium carbonate as sodium oxide). A reduction of resistivity from 1×10^{10} to 1×10^8 ohm cm was measured by another researcher when the sodium oxide content of the ash was increased to 2.5 percent from the inherent 0.3 percent.

Problems—Commercial users have only limited experience with sodium conditioning; therefore, operational problems are not well documented. However, one potential problem associated with adding sodium compound to the coal is slagging and boiler fouling if the system is not operated properly.

Economics—The capital costs for a liquid solution conditioning system are about \$1.55 to \$3.10 per installed kilowatt. The operating costs, excluding depreciation, are about 0.03 mills/kWh.

Conclusions

Of the many agents available, SO_3 is the most commonly used. SO_3 is effective in reducing ash resistivity and will improve the ESP performance if particle resistivity is the limiting factor. The conditioning mechanisms of ammonia, ammonium compounds, and organic amines are not fully understood, and the effectiveness of these compounds is not consistent.

Flue gas conditioning appears to be an acceptable (and the least expensive) option for upgrading ESP performance for collecting high resistivity fly ash. However, before deciding on flue gas conditioning, the reasons for poor ESP performance should be determined. The poor performance could be due to factors other than high resistivity. Once conditioning has been chosen, the conditioning system should be designed and operated with extreme care to avoid harmful emissions due to conditioning agents.

S-C. Yung, R. G. Patterson, B. L. Hancock, and S. Calvert are with Air Pollution Technology, Inc., San Diego, CA 92109.

Leslie E. Sparks is the EPA Project Officer (see below).

The complete report, entitled "Flue Gas Conditioning," (Order No. PB 85-173 912/AS; Cost: \$13.00, subject to change) will be available only from:

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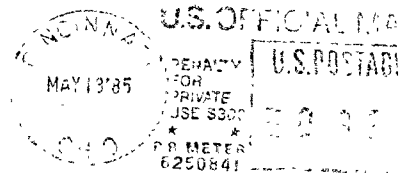
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