DOE/FE-0389

AIRPOL, INC.

10-MWE DEMONSTRATION OF GAS SUSPENSION ABSORPTION

PROJECT PERFORMANCE SUMMARY
CLEAN COAL TECHNOLOGY DEMONSTRATION PROGRAM

JUNE 1999

Disclaimer

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ENVIRONMENTAL CONTROL DEVICES

AIRPOL

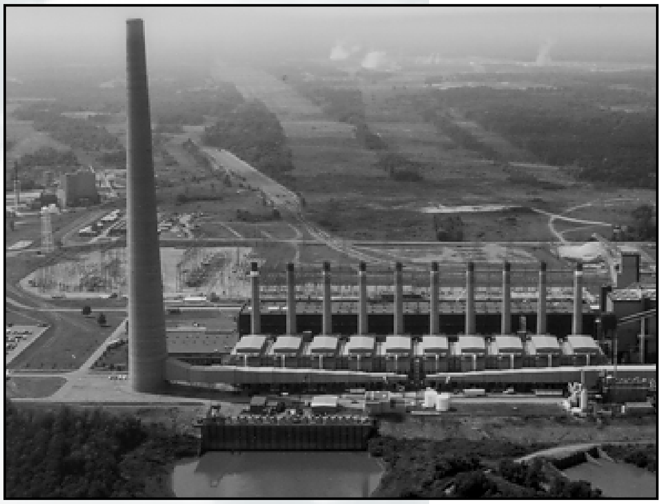
GAS SUSPENSION ABSORPTION PROJECT

OVERVIEW

The unique, compact reactor design provides a low-cost SO_2 regulation compliance option, particularly for small- to moderate-size boilers with space limitations.

A unique flue gas desulfurization (FGD) system, the Gas Suspension Absorption (GSA) reactor developed by AirPol, Inc., underwent its first North American demonstration at Tennessee Valley Authority's Center for Emission Research in Paducah, Kentucky.

The project is part of the U.S. Department of Energy's Clean Coal Technology Demonstration Program (CCTDP) established to address energy and environmental concerns related to coal use. Cost-shared partnerships with industry were sought through five nationally competed solicitations to accelerate commercialization of the most advanced coal-based power generation and pollution control technologies. The CCTDP, valued at nearly $6 billion, has leveraged federal funding twofold through the resultant partnerships encompassing utilities, technology developers, state governments, and research organizations. This project was one of 13 selected in December 1989 from 48 proposals submitted in response to the Program's third solicitation.



GSA's high sulfur-capture efficiency and low lime consumption is the result of an innovative design employing a vertical reactor and integral cyclone particulate separator. The high contact area, excellent mixing, low temperature, and sorbent recycling combine to achieve sulfur capture and sorbent utilization at levels approaching those of wet scrubbers.

Environmental, economic, and system performance objectives for the GSA system were met for the two basic configurations evaluated: GSA with an electrostatic precipitator—GSA/ESP; and GSA with a pulsed jet baghouse—GSA/PJBH.

Both configurations achieved greater than 90 percent SO_2 reduction with high-sulfur coals at calcium-to-sulfur molar ratios (Ca/S) of 1.3–1.4, while controlling particulate emissions at or below 0.015 lb/10^6 Btu (half that of New Source Performance Standards). Economic advantages relative to wet scrubbers and conventional spray dryers were demonstrated. The estimated capital cost for a 300-MWe plant (2.6 percent sulfur coal) was $149/kW, and the 15-year levelized cost was 10.91 mills/kWh (based on 1990 constant dollars). System efficiencies enabled the reactor size to be reduced by 1/4 to 1/3 that of a conventional spray dryer to achieve the same performance.

GSA is particularly applicable to smaller boilers in the range of 50–250 MWe. The compactness of the GSA reactor makes it a particularly attractive SO_2 emissions compliance option for plants with severe space limitations. A number of commercial sales followed completion of the demonstration.

THE PROJECT

With its genesis in preheating cement kiln feedstock, the GSA process evolved into a utility flue gas cleanup system from its first commercial application in Europe to control SO_2 and hydrogen chloride (HCl) emissions from a waste-to-energy plant.

At the time of project inception, there were 10 units in Europe, all installed on municipal solid waste incinerators. The success abroad and its inherent simplicity and efficiency prompted U.S. interest to evaluate GSA technology as a compliance option for the smaller coal-fired boilers facing Phase II Clean Air Act Amendments of 1990 (CAAA) SO_2 reduction requirements. AirPol, Inc., in cooperation with TVA, structured a test program to (1) optimize design of the GSA reactor for reduction of SO_2 emissions from boilers using high-sulfur coal, and (2) evaluate its environmental control capability, economic potential relative to existing systems, and mechanical performance. A statistically designed “factorial” (parametric) test plan was developed involving six basic variables. A total of 78 parametric tests were completed. Beyond evaluation of the basic GSA unit to control SO_2, air toxic control tests were conducted, and the effectiveness of GSA/ESP and GSA/PJBH to control both SO_2 and particulate were tested. Parametric tests were followed by continuous runs to verify consistency of performance over time. The test program schedule is outlined in Figure 1.

Project Sponsor
AirPol, Inc.

Additional Team Members
FLS miljo a/s—parent company of AirPol; technology owner
Tennessee Valley Authority (TVA)—cofunder; site owner

Location
West Paducah, McCracken County, KY
(Tennessee Valley Authority's Center for Emissions Research, Unit 9)

Technology
FLS miljo a/s Gas Suspension Absorption (GSA) system for flue gas desulfurization

Plant Capacity
10-MWe equivalent slipstream from a 175-MWe wall-fired boiler

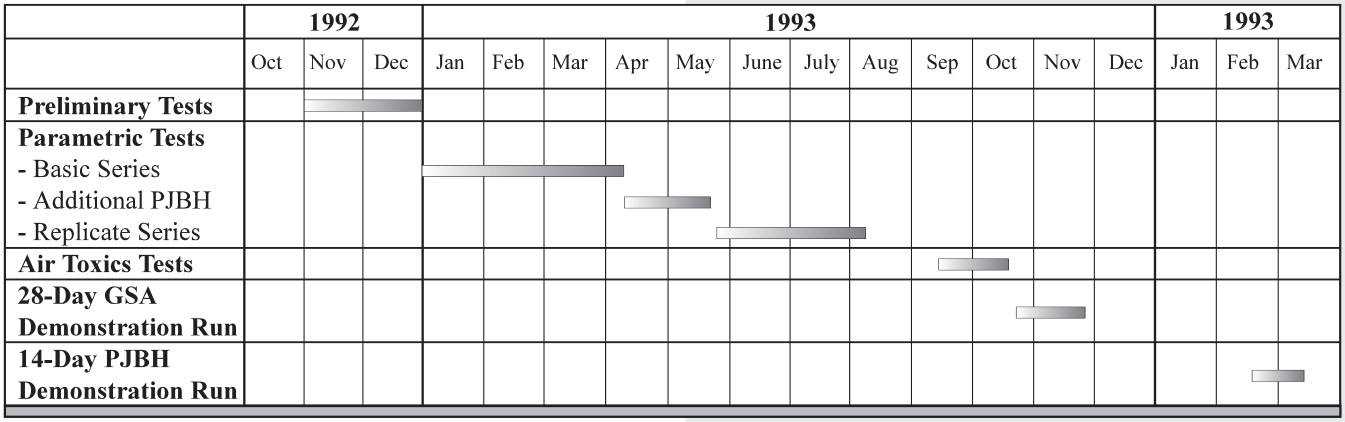
Coals
Western Kentucky bituminous—
  Peabody Martwick, 3.05% sulfur
  Emerald Energy, 2.61% sulfur
  Andalex, 3.06% sulfur
Warrior Basin, 3.5% sulfur (used intermittently)

Demonstration Duration
October 1992–March 1994
Parametric (factorial) tests followed by—
28-day continuous run with ESP
14-day continuous run with PJBH

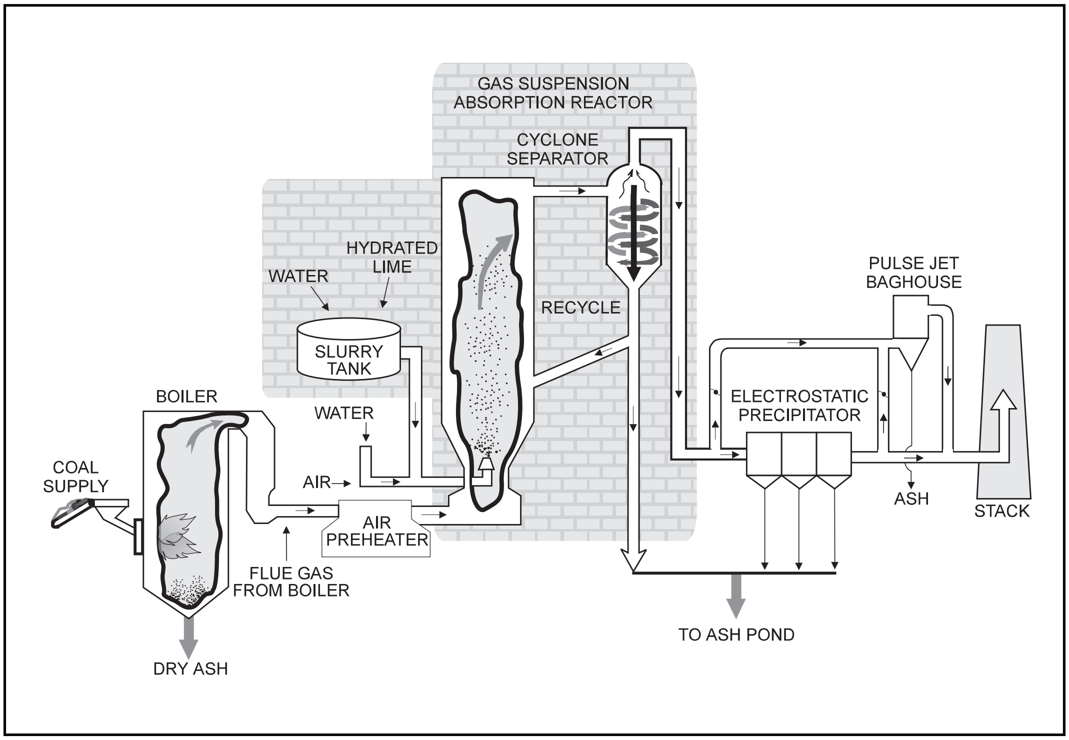
Project Funding

Total project cost	$7,717,189	100%
DOE	2,315,529	30%
Participant	5,401,930	70%

FIGURE 1. DOE/AIRPOL/TVA TEST PROGRAM



The Technology



Flue gas enters the bottom of the reactor and flows co-currently upwards with recycled solids and fresh lime slurry. The lime slurry is fed into the reactor by means of a single spray nozzle mounted in the throat of the reactor, which sprays the lime slurry vertically upwards through the center of the reactor. The spray droplets, consisting of water and lime particles, coat the surface of the recycled solids suspended in the flue gas stream. The suspended solids provide a medium with a large surface area for reaction of the lime with acid gases, such as HCl, hydrogen flouride (HF), and SO_2. At the same time, water evaporates from the surface of the solids, simultaneously cooling the flue gas and drying the solids.

The dry solids, consisting of lime, reaction products, and fly ash, are entrained in the flue gas and pass up through the reactor and into a cyclone separator. Approximately 99 percent of the solids entering the cyclone are recycled back to the reactor via a feeder box, which provides temporary in-process storage. The high concentration of solids being recycled through the reactor enables rapid evaporation of water from the slurry and minimizes scaling on the reactor walls due to scouring by the solids. The high heat and mass transfer provided by the turbulent, entrained flow allows effective drying so that lower temperatures conducive to sulfur capture can be used. Unused lime in the recycled solids can further react with acid gases in the flue gas, lowering the overall consumption of lime. The volume of lime slurry is regulated with a variable speed pump controlled by measurement of acid content in the inlet and outlet streams. Dilution water is controlled by measurement of flue gas exit temperature.

The flue gas containing the remaining 1 percent of the solids leaving the cyclone enters an ESP for final particulate collection. After passing through the ESP, the cleaned flue gas is released to the stack. The GSA reactor is distinguished from the average spray dryer by its modest size, simple means of introducing reagent to the reactor, direct means of recirculating unused lime, and low reagent consumption. Also, because the injected slurry coats recycled solids and not the walls, corrosion is avoided and carbon steel can be used in fabrication.

DEMONSTRATION RESULTS

- Ca/S (moles $Ca(OH)_2$/mole SO_2) had the greatest effect on SO_2 removal, with approach-to-saturation temperature next, followed closely by chloride content.
- GSA/ESP achieved 90 percent sulfur capture at a Ca/S of 1.3 with an 8 ºF approach to saturation and low chloride level (0.02–0.04 percent). To achieve the same sulfur capture with an 18 ºF approach to saturation and moderate chloride level (0.12 percent), a Ca/S of 1.4 was required. Particulate removal efficiency averaged 99.9+ percent.
- GSA/PJBH achieved 96 percent sulfur capture at a Ca/S of 1.4 with an 18 ºF approach to saturation and moderate chloride level (0.12 percent). Overall, GSA/PJBH demonstrated a 3–5 percent increase in SO_2 reduction relative to GSA/ESP. Particulate removal efficiency averaged 99.99+ percent.
- Both GSA/ESP and GSA/PJBH removed 98 percent of the HCl and 96 percent of the HF, as well as 99 percent of most trace metals, with the exception of cadmium, antimony, mercury, and selenium. (GSA/PJBH removed 99 percent of the selenium, while GSA/ESP did not.)
- GSA/ESP lime utilization averaged 66.1 percent and GSA/PJBH averaged 70.5 percent.
- The GSA reactor achieved the same performance as a conventional spray dryer but at 1/4 to 1/3 the size, and generated less particulate matter than a spray dryer, enabling compliance with a lower ESP efficiency. Also, no special steels are required in construction and only a single spray nozzle is needed.
- For a 300-MWe plant using 2.6 percent sulfur coal, the Electric Power Research Institute's (EPRI) cost methodology estimates the capital cost for the GSA system at $149/kW with a spare module and $126/kW without a spare. Levelized costs (over a 15-year period) are estimated at 10.91 mills/kWh with a spare and 6.8 mills/kWh without. (All costs in 1990 constant dollars.)

APPROACH

Table 1 lists the six variables used in the parametric tests and the levels at which they were applied. The inlet flue gas temperature was held constant at 320 ºF. Decisions on parameters were based on TVA's experience with other dry, lime-based FGD systems and results from preliminary tests.

TABLE 1. MAJOR VARIABLES AND LEVELS FOR GSA FACTORIAL TESTING

Variable	Level
Approach-to-saturation temperature (°F)	8*, 18, 28
Ca/S (moles $Ca(OH)_2$/mole inlet SO_2)	1.00 and 1.30
Flyash loading (gr/ft^3 [actual])	0.50 and 2.0
Coal chloride level (%)	0.02 and 0.12
Flue gas flow rate (10^3 std ft^3/min)	14 and 20
Recycle screw speed (rpm)	30 and 45

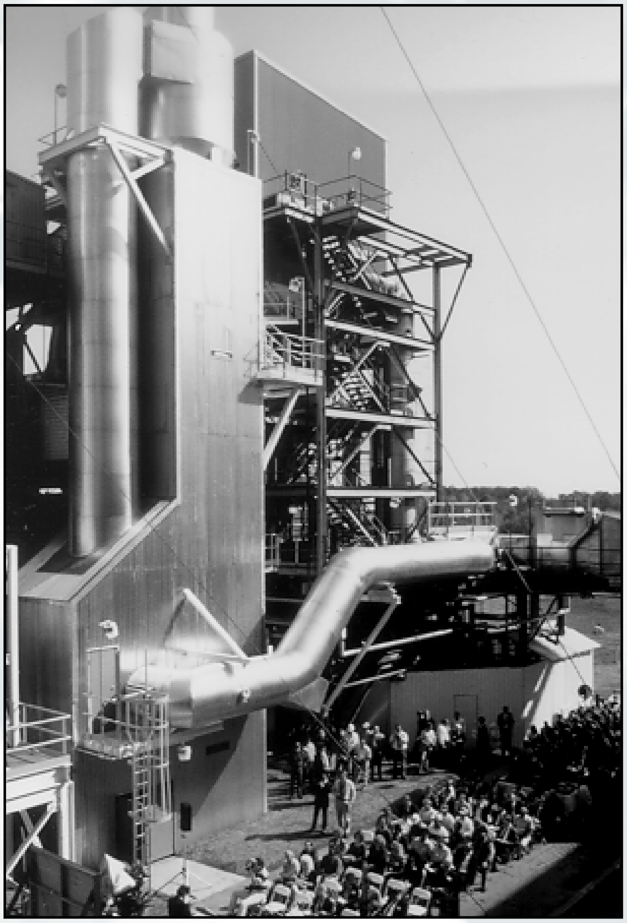
* The 8 °F condition was run only at the low coal-chloride level.

Parametric Tests—A total of 78 tests were performed during the parametric test phase. Basic and replicate tests included runs with the ESP and PJBH both in series and in parallel. Additional unplanned runs were made to address PJBH performance. A typical test consisted of 12–24 hours of operation to reach steady state, followed by 24–48 hours at steady state, during which the data were taken. Chloride spiking with calcium chloride was used to achieve the higher 0.12 percent chloride level representative of many coals.

28-Day Run—The 28-day run to evaluate the GSA/ESP configuration was essentially continuous with a short disruption due to a boiler tube leak. The run was performed with the single set of operating conditions outlined below:

- Western Kentucky coals averaging 2.7 percent sulfur and 0.04 percent chloride (for all but one week during which a 3.5 percent sulfur Warrior Basin coal was used)
- SO_2 removal set point of 91 percent
- 18 ºF approach-to-saturation temperature
- 20,000 std ft^3/min flue gas flow rate at inlet
- 320 ºF inlet flue gas temperature
- 30 rpm recycle screw speed
- Flyash injection rate equivalent to 1.5 gr/ft^3 (actual)
- Calcium chloride spiking to simulate coal with 0.12 percent chlorine (by weight)
- Lime slurry solids concentration of 25 percent

Fresh lime stoichiometry was allowed to fluctuate to meet the 91 percent SO_2 reduction set point for 7 of the 9 test segments. During segments 7 and 8, the stoichiometry was fixed at 1.40 and 1.45 moles of $Ca(OH)_2$/mole of inlet SO_2, respectively.



GSA reactor with integral cyclone installed in housing

14-Day Run—The conditions for the 14-day run to evaluate the GSA/PJBH configuration were the same as that for the 28-day run except for adjustments in flyash injection rate from 1.5 gr/ft^3 (actual) to 1.0 gr/ft^3. The change was made to adjust for the coal used and overages above design baselines suspected in the 28-day run. The PJBH and ESP were run in parallel to obtain direct performance comparisons.

Air Toxic Testing—All tests were conducted with 2.7 percent sulfur, low-chloride Andalex coal and were run at a flue gas flow rate of 20,000 std ft^3/min and a high flyash loading of 2.0 gr/ft^3. Baseline tests without injecting lime slurry were performed at 270 °F GSA reactor inlet temperature to protect the acrylic bags in the PJBH. Demonstration tests operated at 320 °F GSA reactor inlet temperature, with a 12 °F approach-to-saturation temperature at the GSA outlet.

ENVIRONMENTAL PERFORMANCE

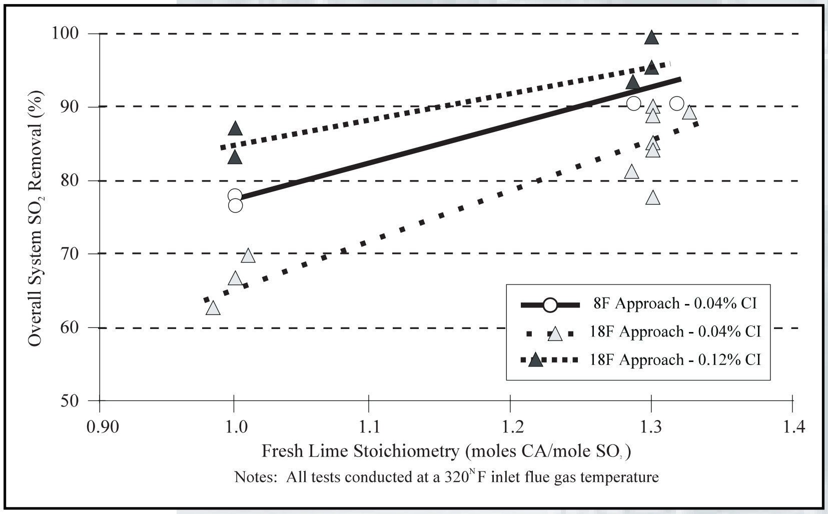
Parametric Tests—Parametric testing showed that lime stoichiometry had the greatest effect on SO_2 removal. Approach-to-saturation temperature was the next most important factor, followed closely by chloride levels. Flue gas flow rate, recycle screw speed, and flyash loading had minor effects on performance. Although an approach-to-saturation temperature of 8 °F was achieved without plugging the system, the test was conducted at a very low chloride level (0.04 percent). (Water evaporation rates decrease as chloride levels increase.) To run the system at the higher 0.12 percent coal-chloride level, an 18 °F approach-to-saturation temperature was chosen. This proved to be an effective combination. The average moisture content in the solids remained below 1.0 percent.

Flue gas slipstream ductwork

Figure 2 summarizes key results from parametric testing (including some model projections that match well) of the GSA in combination with the ESP. The ESP is fairly representative of modern, four-field units. The specific collection area was about 440 ft^2 per thousand ft^3/min of actual flow under cooled, humidified flue gas conditions. The GSA reactor/cyclone was responsible for most of the SO_2 removal, with only 2–5 percent occurring in the ESP.

The examination of GSA/ESP performance relative to previous tests on a spray dryer/ESP system showed that while overall SO_2 removal was comparable, GSA was more efficient, removing a far greater percentage of the SO_2. However, the ESP in combination with GSA displayed lower SO_2 removal efficiency. This was attributed to the very low moisture in the particulate, a smaller size distribution, and lower grain loading entering the ESP.

FIGURE 2. OVERALL SYSTEM SO_2 REMOVAL RESULTS FOR THE GSA/ESP CONFIGURATION



Notes: All tests conducted at a 320^{N}F inlet flue gas temperature

28-Day Run—The 28-day run on the GSA/ESP system showed the following results:

- The overall SO_2 removal efficiency averaged slightly more than 90 percent, very close to the set point, at an average Ca/S of 1.40–1.45 (moles of $Ca(OH)_2$/mole of inlet SO_2).
- The system was able to adjust rapidly to the surge in inlet SO_2 caused by switching to 3.5 percent Warrior Basin coal.
- Lime utilization averaged 66.1 percent.
- The particulate removal efficiency averaged 99.9+ percent and emission rates were maintained at less than 0.015 lb/10^6 Btu.
- The system reflected the high reliability and availability demonstrated in similar commercial applications by staying on-line throughout the test.

14-Day Run—The 14-day run on the GSA/PJBH system showed the following results:

- The SO_2 removal efficiency averaged 96+ percent at an average Ca/S of 1.34–1.43 moles of ($Ca(OH)_2$/mole of inlet SO_2).
- Lime utilization averaged 70.5 percent.
- The particulate removal efficiency averaged 99.99+ percent and emission rates ranged from 0.001 to 0.003 lb/10^6 Btu.

Comparison to Conventional Spray Dryer—The GSA system is more efficient than a conventional spray dryer and, therefore, can achieve the same SO_2 removal at 1/4 to 1/3 the size. Also, the GSA system generates a significantly lower particulate matter loading than a spray dryer—2–5 versus 6–10 gr/ft^3 (actual)—enabling compliance with lower ESP particulate removal efficiency.

Air Toxic Testing—The GSA/ESP arrangement indicated average removal efficiencies of 99+ percent for arsenic, barium, chromium, lead, and vanadium. Removal efficiencies were somewhat less than 99 percent for manganese, antimony, cadmium, mercury, and selenium. Mercury levels were close to detection limits, while most antimony measurements were below detection limits.

Pulsed Jet Baghouse (left), ESP (center), and GSA System (right)

The GSA/PJBH configuration showed 99+ percent removal efficiencies for arsenic, barium, chromium, lead, manganese, selenium, and vanadium. Cadmium removal efficiency was much lower with this arrangement than any other arrangement in both baseline and demonstration tests. Mercury removal efficiency was lower than that of the GSA/ESP system.

HCl and HF removal was dependent upon the utilization of lime slurry and was relatively independent of particulate control configuration. The removal efficiencies were 98+ percent for HCl and 96+ percent for HF.

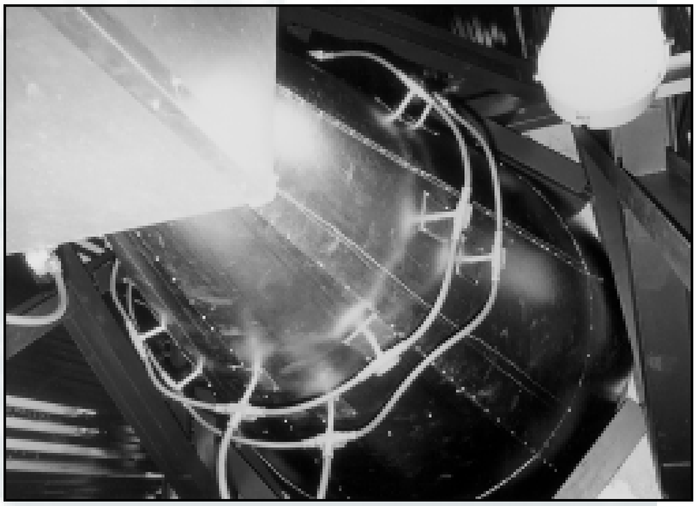
OPERATIONAL PERFORMANCE

The GSA system performed well throughout the demonstration, consistent with the high availability and reliability achieved in similar commercial applications and reflective of the simple, effective design. The suspended recycle solids in the GSA system provide a contact area for SO_2 capture. This precludes the need for multiple high-pressure atomizer nozzles or high-speed rotary nozzles which would be required to achieve uniform, fine droplet size . Also, the direct recycle of solids with an integral cyclone avoids recycling material in the feed slurry, which would necessitate expensive abrasion-resistant materials in the atomizer(s).


Cyclone Separator

The GSA reactor provides in SO_2 control comparable to wet scrubbers with high lime utilization (up to 80 percent). This performance results from the capability of suspending a high concentration of solids, effectively drying the solids, and recirculating the solids at a high rate with precise control. GSA's high concentration of solids provides the sorbent/SO_2 contact area. The drying enables low approach-to-saturation temperature and chloride usage. The rapid, precise integral recycle system sustains the high solids concentration. The high lime utilization mitigates the largest operating cost —lime— and further reduces costs by reducing the amount of by-product generated.

The high heat and mass transfer characteristics of GSA allows low flue gas residence time. This, combined with the high flue gas velocity, enables the GSA system to be significantly smaller—1/4 to 1/3 the size of a conventional spray dryer for the same capacity. This makes retrofit feasible for space-confined plants and reduces the cost of installation.



Bottom of cyclone separator where it attaches to collection box; captured solids are either recycled to GSA or drawn off as waste

The GSA system slurry is sprayed on the recycled solids, not the reactor walls, avoiding direct wall contact and the need for corrosion-resistant alloy steels. Furthermore, the high concentration of rapidly moving solids scours the reactor walls and mitigates scaling.

The GSA system produces a solid by-product containing very low moisture. This material contains both fly ash and unreacted lime. With the addition of water, the by-product undergoes a pozzolanic reaction, essentially providing the characteristics of a low-grade cement, which may have application in landfills and other construction applications where stabilization is required.

ECONOMIC PERFORMANCE

Using the Electric Power Research Institute (EPRI) costing methodology applied to 30–35 other FGD processes, economics were estimated for a moderately difficult retrofit of a 300-MWe boiler burning 2.6 percent sulfur coal. The design SO_2 removal efficiency was 90 percent at a lime feed rate equivalent to 1.30 moles of Ca/ mole of SO_2 in the gas inlet stream. Lime was assumed to be 2.8 times the cost of limestone. The following costs were determined:

- Capital cost (1990$)
  - –$149/kW with 3 units at 50 percent capacity
  - –$126/kW with no spare units
- Levelized cost (15-year period; 1990$)
  - –10.91 mills/kWh with 3 units at 50 percent capacity
  - –6.8 mills/kWh with no spare units

A cost comparison performed for a wet limestone forced oxidation scrubber showed the capital and levelized costs to be $216/kW and 13.04 mills/kWh, respectively. The capital cost listed in EPRI cost tables for a conventional spray dryer at 300 MWe, 2.6 percent sulfur coal, and 1990 constant dollars, is $172/kW. Also, because GSA requires less power and has better lime utilization than a spray dryer, the GSA system will have lower operating cost.

COMMERCIAL APPLICATIONS

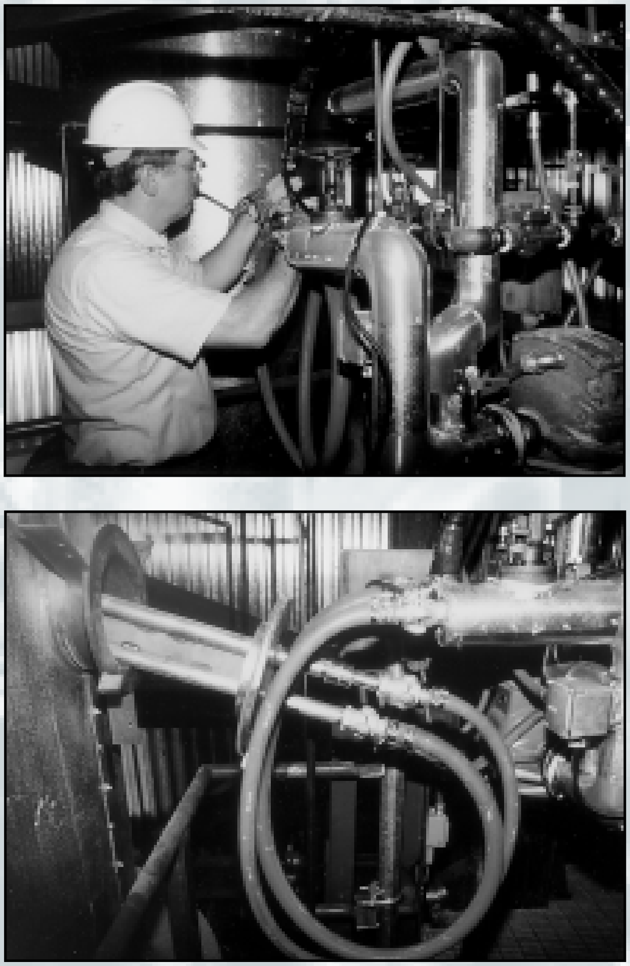
The low capital cost, moderate operating cost, and high SO_2 capture efficiency make the GSA system particularly attractive as a CAAA compliance option for boilers in the 50 to 250-MWe range. Other major advantages include the modest space requirements comparable to duct injection systems, high availability/reliability owing to design simplicity, and low dust loading that minimizes particulate emission control upgrade costs.

Within three years of the demonstration, commercial sales were made to the City of Hamilton, Ohio for a 50-MWe unit, the U.S. Army for a hazardous waste disposal application, Sweden for a 4-million ton/year iron ore sinter plant, and Taiwan and India for units valued at $33 million.

TVA provided some guidance, in regard to the commercial design, that centered on slaking the lime. TVA suggested that consideration be given to the following recommendations:

- Eliminating the detention slaking process, whereby grit is removed from the pebble lime, to avoid production of additional wastewater
- Providing an effective means of dealing with the wastewater/grit stream
- Developing an abrasion resistant nozzle, which would be required if the slaking process is eliminated

Also, concern was expressed regarding use of cooling tower blowdown for slaking because the high salt content may lower lime utilization (the primary operating cost consideration). It was suggested that a study be made on the impact of using the blowdown water.



Workman Removing GSA Nozzle for Inspection

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