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SOUTHERN COMPANY SERVICES, INC.

DEMONSTRATION OF INNOVATIVE APPLICATIONS OF TECHNOLOGY FOR THE CT-121 FGD PROCESS

PROJECT PERFORMANCE SUMMARY
CLEAN COAL TECHNOLOGY DEMONSTRATION PROGRAM

AUGUST 2002

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ENVIRONMENTAL CONTROL DEVICES

Demonstration of Innovative Applications of Technology for the CT-121 FGD Process

The CT-121 FGD process eliminated the need for a spare module and proved effective in removing particulate matter and hazardous air pollutants. The fiberglass-reinforced plastic construction eliminated the need for pre-scrubbing and reheat of the treated flue gas.

Overview

This project is part of the U.S. Department of Energy's (DOE) Clean Coal Technology Demonstration Program (CCTDP) established to address energy and environmental concerns related to coal use. DOE sought cost-shared partnerships with industry through five nationally competed solicitations to accelerate commercialization of the most promising advanced coal-based power generation and pollution control technologies. The CCTDP, valued at over five billion dollars, has significantly leveraged federal funding by forging effective partnerships founded on sound principles. For every federal dollar invested, CCTDP participants have invested two dollars. These participants include utilities, technology developers, state governments, and research organizations. The project presented here was one of sixteen selected from 55 proposals submitted in 1988 and 1989 in response to the CCTDP second solicitation.

Southern Company Services, Inc. teamed with the Electric Power Research Institute (EPRI) to demonstrate the Chiyoda Thoroughbred-121 (CT-121) flue gas desulfurization (FGD) process at Georgia Power Company's Plant Yates in Newnan, Georgia. Georgia Power Company fabricated the CT-121 on-site, using fiberglass-reinforced plastic (FRP) construction, to process all the flue gas from the 100-MWe Unit 1 boiler. Interest in the project stemmed from the unique Jet Bubbling Reactor system, which integrates a number of scrubber process steps into a single process reactor and lends itself to particulate capture.

The demonstration of the CT-121 scrubber technology was highly successful. For over 17,000 hours of operation, the CT-121 averaged 97% availability and provided over 90% SO_2 removal, 97–99% particulate removal, and high air toxics removal efficiencies under conditions of varying coal sulfur content, limestone sources, and ash loading. The FRP construction performed admirably, proving to be chemically and physically durable.

At the conclusion of the demonstration period in December of 1994, Georgia Power chose to assume responsibility for the cost and operation of the CT-121 flue gas desulfurization system on their own. This action preserved the scrubber's contribution to Georgia Power's overall commitment to environmental protection. As of the date of this publication, CT-121 systems are operating at 17 plants in 8 countries and 5 projects are either in design or under construction.

The CT-121 project has received four awards from industry and environmental groups for its performance. *Power* magazine presented the project the 1994 Powerplant Award, with DOE as the co-recipient. The Georgia Chamber of Commerce honored the project with its 1993 Environmental Award. The Georgia Air and Waste Management Association presented the project its 1994 Outstanding Achievement Award. And in 1995, the project received the Design Award from the Society of Plastics Industries.

The Project

The project began as an experiment with innovative improvements to an existing Chiyoda Corporation CT-121 Jet Bubbling Reactor (JBR) wet limestone SO_2 scrubbing system. The process is a simplified wet scrubber that reduces capital costs by allowing the chemical reactions to occur in a single vessel at reaction rates and times that encourage complete reactant usage, and complete product conversion to a usable byproduct. The CT-121 differs from the more common spray tower type of flue gas desulfurization system in that a single process vessel takes the place of the usual spray tower/reaction tank/thickener arrangement. CT-121 process simplicity also precludes the need for a spare module and associated capital and operating costs. The challenge was to ensure reliable, environmentally proficient, and economically advantageous operations with the least amount of equipment. The CT-121 met this challenge and exceeded expectations.

The major objectives of the CT-121 project were to:

- Construct major CT-121 components on site using fiberglass reinforced plastics;
- Operate the CT-121 process without a spare absorber;
- Operate the CT-121 process without a pre-scrubber to remove chlorides;
- Operate the CT-121 process without reheat;
- Test simultaneous particulate/SO_2 removal by the CT-121 JBR; and
- Evaluate "stacking" of the gypsum byproduct as a disposal option.

As the project progressed, the objectives expanded to include the full range of JBR particulate collection capabilities, the measurement of air toxics removal across the JBR, the impact of various limestones on performance, and the impact of coals of various sulfur contents on performance.

Construction at Plant Yates began in late 1990, startup was in the fall of 1992, and testing continued through the end of 1994.

Project Sponsor
Southern Company Services, Inc.

Additional Team Members
Georgia Power Company – *host*
Electric Power Research Institute – *cofounder*
Radian Corporation – *consultant*
Ershigs, Inc. – *fiberglass fabricator*
Composite Construction and Equipment – *consultant*
Acentech – *consultant*
University of Georgia's Research Foundation – *consultant*

Location
Newnan, Coeta County, Georgia (Plant Yates Unit No. 1)

Technology
Chiyoda Corporation's CT-121 advanced flue gas desulfurization process

Plant Capacity/Production
100 MWe

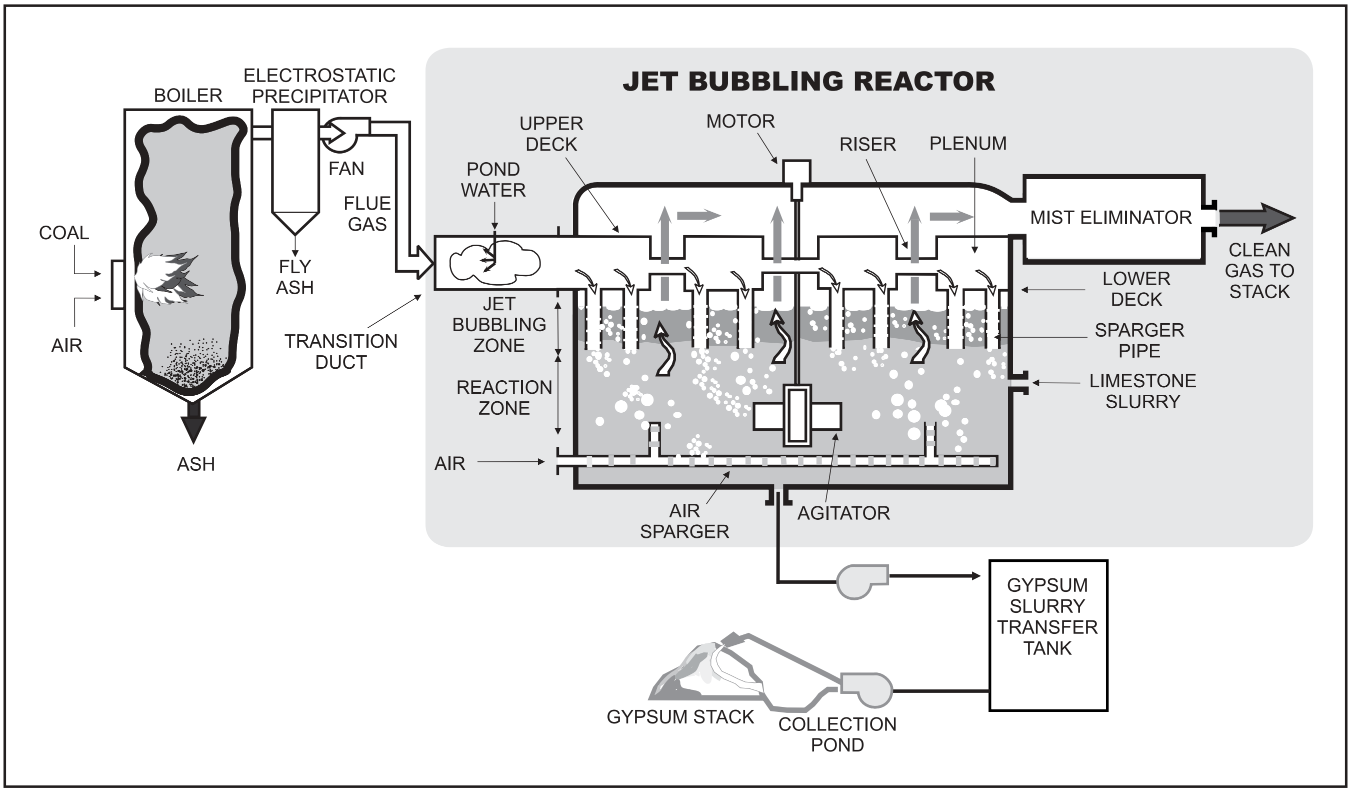
Coal
Illinois No. 5 and No. 6 blend, 2.5% sulfur (baseline)
Range of coals 1.2% - 4.3% sulfur

Demonstration Duration
October 1992 - December 1994

Project Funding

Total Project Cost	$43,074,996
DOE	21,085,211
Participant	21,989,785

The Technology



The heart of the CT-121 is the JBR, which is shown in the shaded area of the above diagram. The JBR combines SO_2 absorption and neutralization, sulfite oxidation, and gypsum crystallization in one reaction vessel.

Flue gas from the electrostatic precipitator (ESP), pressurized by induced draft and scrubber booster fans, enters a gas cooling section — the transition duct. Here flue gas is cooled with gypsum recycle pond water at a liquid-to-gas ratio of 0.25 gallons (gal)/1000 actual cubic feet (acf) of flue gas to prevent a wet-dry interface from occurring between the slurry and flue gas. The flue gas is then completely saturated by spraying JBR slurry concurrently with gas stream flow at a liquid-to-gas ratio of about 10 gal/1000 acf at full boiler load.

After cooling, the flue gas enters the JBR in an enclosed plenum chamber formed by an upper deck plate and a lower deck plate. Sparger tube openings in the lower deck plate force the gas into the slurry contained in the jet bubbling (froth) zone of the JBR vessel. After bubbling through the slurry, the gas flows upward through gas risers, which pass through both the lower and upper deck plates. The contacting of hot flue gases with neutralizing limestone slurry relies on a “sparging” action — an effect like that created when air is blown through a straw into a glass of water.

SO_2 absorption occurs in the froth zones that are formed when the untreated gas is accelerated through sparger tubes in the lower deck and bubbled beneath the surface of the slurry at a depth of 8 to 20 inches. The froth zone provides the gas-liquid interfacial area for SO_2 mass transfer to the slurry, as well as particulate removal. The bubbles in the froth zone are continually collapsing and reforming to generate new and fresh interfacial areas and to transport reaction products away from the froth zone to the reaction zone.

SO_2 removal is controlled by changing the JBR slurry level, which controls the amount of interfacial area and gas residence time, and by changing the pH of the slurry in the froth zone, which affects alkalinity, with higher alkalinity more rapidly neutralizing the absorbed SO_2.

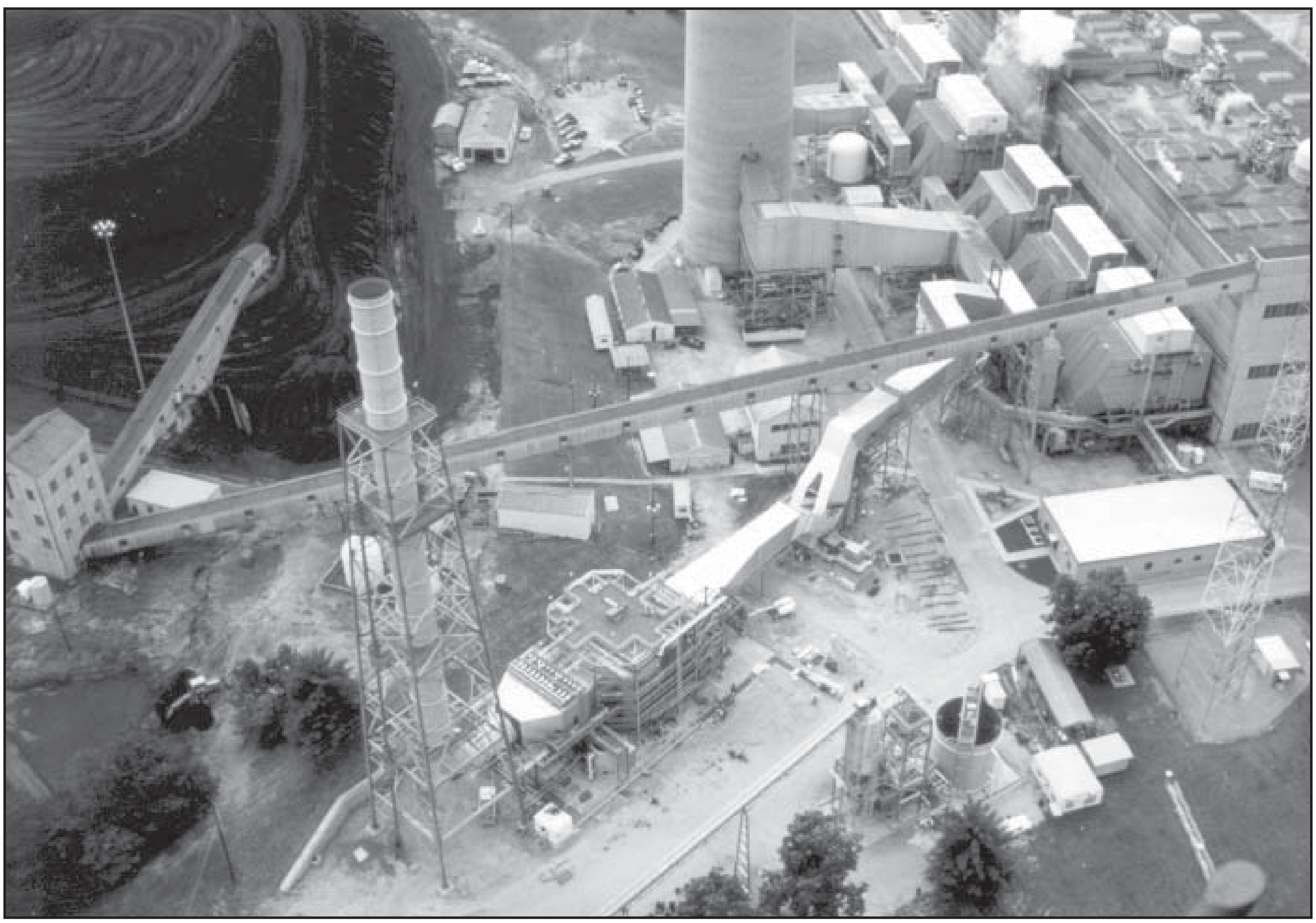
The pH is controlled by the amount of limestone fed to the reaction zone of the JBR, which is ground to 90% passing a 200-mesh screen to ensure rapid reaction. The process is designed to operate in a pH range (3 to 5) where the driving force for limestone dissolution is high, resulting in nearly complete reagent utilization. Oxidation of sulfite to sulfate is also promoted at the lower pH because of the increased solubility of naturally occurring catalysts such as iron. The solids concentration in the JBR is maintained by periodically removing slurry from the bottom of the reaction zone and pumping this stream to a gypsum slurry transfer tank, where it is diluted with pond water before being pumped to the gypsum stack.

Forced oxidation air lines introduce the air near the bottom of the JBR. Oxidation air is first saturated with process water to prevent a wet-dry interface at the discharge of the oxidation air lines. Oxygen diffuses from the air into the slurry as the bubbles rise to the froth zone of the JBR. Excess air mixes with the flue gas and enters a second plenum above the upper deck plate, where velocity decreases and entrained slurry (liquor) disengages. A horizontal flow mist eliminator captures vapor-state liquor.

After leaving the mist eliminator, the clean gas exits through a wet chimney, which captures condensation from the saturated gas stream and returns it to the JBR. This capture is accomplished by a system of gutters attached to the inside of the chimney that channel the condensate to a grate and drain section located in the elbow of the chimney, which provides a dead zone in the gas path.

The gypsum stacking technique involves filling a high-density polyethylene (HDPE) lined diked area with slurry for gravity sedimentation. The settled gypsum is then partially excavated to increase the height of the containment dikes. The process of sedimentation, excavation, and raising perimeter dikes continues on a regular basis during the active life of the stack. Process water is decanted, stored in a gypsum recycle water pond, and then returned to the process.

The forced oxidation system provides sufficient surface area for gypsum crystal growth and prevents the system from becoming supersaturated with calcium sulfate. This approach significantly reduces the potential for gypsum scaling, a problem that frequently occurs in natural-oxidation FGD systems and many conventional forced systems. Unlike conventional systems, pumping of reacted slurry to a gypsum transfer tank is only intermittent, allowing crystal growth to proceed relatively uninterrupted and resulting in large, easily dewatered gypsum crystals.



Aerial view of CT-121 installation at Plant Yates

JBR with stack rising above

Results Summary

Environmental

- Over 90% SO_2 removal efficiency was achieved at SO_2 inlet concentrations of 1,000 – 3,500 ppm with limestone utilization over 97%
- JBR particulate removal efficiencies were consistently above 97% for all test conditions and usually in excess of 99%.
- Particulate capture efficiency was > 99% for particulate > 2.0 microns; dropped dramatically for particulate 0.6 to 1.0 microns (~82% at 1.0 microns); was negligible for particulate 0.3 to 0.6 microns; and picked up again below 0.3 microns.
- Hazardous air pollutant (HAP) testing showed greater than 99% capture of hydrogen chloride (HCL) and 98% capture of hydrogen fluoride (HF) gases, 84 – 96% capture of most trace metals, approximately 46% capture of mercury and cadmium, and 67% capture of selenium.
- Gypsum stacking proved effective for producing wallboard and cement-grade gypsum.

Operational

- FRP-fabricated equipment proved durable both structurally and chemically, eliminating the need for a flue gas prescrubber and reheat.
- FRP construction combined with simplicity of design resulted in 97% availability over the course of the demonstration, eliminating the need for a spare reactor module.
- Simultaneous SO_2 and particulate control were achieved at fly ash loadings similar to those of an electrostatic precipitator (ESP) that has marginal performance.

Economic

- Capital costs for project equipment, process, and startup were $29.3 million, or $293/kW at Plant Yates.
- Fixed O&M costs were $357,000/yr (1994$), and variable operating costs were $34 – 64/ton of SO_2 removed, depending on specific test conditions.
- Projected capital costs for commercial implementation of the CT-121 process are in the range of $80 – $95/kW. Levelized cost estimates are not available.

Operational Performance

The CT-121 demonstration evaluated the system over a full range of conditions that might be expected in a variety of service applications. Testing included conditions outside of recommended operating parameters to assess durability and performance potential. Over the course of more than 17,000 hours of actual testing, the CT-121 proved to be durable, reliable, and forgiving.

The CT-121 process evaluation was divided into two distinct periods: a low-particulate and a high particulate test period. Each of these test periods was further divided into a series of three test blocks: Parametric, Long-Term, and Auxiliary Test blocks. Low-particulate testing was conducted with the ESP set for optimum performance, which resulted in a typical particulate mass loading at the JBR inlet of 0.07 lb/10^6 Btu. High ash testing included periods with the ESP shut down, but the bulk of the operation was with the ESP performing at about 90% efficiency to simulate applications with marginal ESPs. Typical particulate mass loading at the JBR inlet with the ESP shut down was 5.0 lb/10^6 Btu and 0.9 lb/10^6 Btu at 90% ESP efficiency. Parametric tests characterized the performance of the process as a function of controllable parameters, such as slurry pH, JBR $\triangle$P (pressure differential across the JBR), and boiler load. Long-term tests evaluated the process performance in achieving set SO_2 removal efficiencies under load following and transient start-up, process upset, and rapid load change modes. Auxiliary tests assessed CT-121 performance with a variety of limestones and coals, and process performance at the highest possible SO_2 removal efficiency.

Both availability and reliability of the CT-121 over the course of the entire process evaluation was 97%. Availability and reliability in the low-ash period averaged over 98%. During high ash testing, availability and reliability dropped to an average 95%. Under conditions of full fly ash loading corresponding to the ESP being completely de-energized, the CT-121 availability and reliability dropped to 92% and evidence suggested that the scrubber could not sustain such conditions in the long term. The CT-121 sustained the de-tuned, 90% efficient ESP conditions at nearly 97% availability and reliability.

Much of the scrubber unavailability was related to failures in auxiliary systems that were not directly associated with the CT-121 process or resulted from abnormal test conditions. Major contributors included rupture of the HDPE slurry transfer pipe due to an installation error, scaling problems following parametric testing at conditions outside of

Limestone unloading conveyor and slurry tank

Fiberglass being applied in FRP construction

Epoxy resin being applied in FRP construction

recommended JBR operating parameters, and a latent defect in the design of the limestone ball mill lube oil system.

However, a number of improvements were recommended to enhance performance and availability of the CT-121 system. While the FRP construction proved to be durable both structurally and chemically overall, local erosion of the FRP materials did occur in the gas cooling transition duct and JBR inlet plenum, requiring repair during planned outages. Another somewhat related problem was solids build-up on the lower deck of the JBR inlet plenum, leading to sparger tube plugging under high ash loading situations. For new installations, the primary fix suggested to alleviate both the JBR inlet wear and solids build-up problems was to relocate the gas cooling section further upstream. The relocation would allow the high solids content slurry to fall to the duct floor and be removed prior to entering and impacting vertical JBR inlet surfaces. The transition duct and JBR inlet erosion at Plant Yates prompted coating of the high ware areas with Duromar® or Duromix® to reduce the ware rate. To further address solids build-up and sparger tube plugging, recommendations were to eliminate the 4-inch rise of the sparger tubes above the floor of the inlet plenum, making them flush, and to improve the wash system by providing overlapping coverage.

Despite some local erosion problems, FRP construction proved to be a distinct advantage. In general, the wide use of FRP for this highly abrasive, high chloride, closed-loop environment was successful. Use of FRP simplified the process and reduced capital and operating costs by precluding the need for a spare module, the need to pre-scrub for chlorides removal to protect metal alloys, and the need to reheat flue gas. FRP also enabled use of a closed loop system and low pH to enhance limestone utilization.

The 40 silicon carbide gas cooling nozzles, each with a 3/8-inch free-pass area proved to be prone to plugging from scale and debris falling to the floor of the JBR. This was resolved by installing a "hockey net" style cooling pump suction screen with a 3/8-inch free pass.

The two key process control systems, pH and JBR level control, were not initially as successful as anticipated. Of the two pH measurement devices, only the Van London probe/Rosemount transmitter arrangement worked well. The pH control circuit's transient response was improved through the use of feedforward-feedback control. Reliable redundant readings were obtained only after the pH probes were located adjacent to one another. For future applications, it was recommended that provision be made for removing, calibrating, and replacing pH probes while the JBR is on-line (hot taps). JBR level control using three different pressure instruments was unreliable because these instruments were prone to plugging, which resulted in erroneous readings. To resolve this problem, the existing JBR gas-side differential pressure instrument was used as a surrogate for JBR level. This system worked well, and although no redundant instrumentation was available, no problems were experienced. Gas side differential pressure is not always proportional to JBR level, however, and may require adjustment to maintain a constant SO_2 removal efficiency under changing boiler load conditions. For future applications, it was recommended that use of alternate kinds of liquid level-based differential pressure instruments be explored.

The Yates CT-121 process maintained high limestone utilization (typically greater than 97%) while achieving high SO_2 removal efficiency. Because of the unique JBR design, the CT-121 process can operate at a lower pH than conventional spray tower wet limestone FGD processes while still attaining excellent SO_2 efficiency. Low pH dissolves the limestone that would otherwise react directly with SO_2 on JBR surfaces to form gypsum scale. Under low-particulate conditions, it was determined that pH could be raised as high as 5.3 before any significant decrease in limestone utilization was observed. Due to the design of the CT-121 process, however, little improvement in SO_2 removal efficiency is realized by raising pH above 4.5. A limestone grind size of 90% passing 200 mesh was adopted because coarser grind sizes showed no economic benefit and slightly lowered utilization at higher pHs. During high ash testing, elevated aluminum and fluoride concentration in the scrubbing liquor resulted in inhibited limestone dissolution. To insure greater than 97% limestone utilization when operating under elevated aluminum and fluoride concentrations, the pH range was restricted to 4.0 or lower.

Throughout the performance evaluation, parameters such as coal source, coal sulfur content, and limestone source were varied. The purpose of investigating these variations was to determine if the CT-121 process was a viable SO_2 and particulate removal technology not only at Plant Yates but at other potential sites as well. By evaluating different coal and limestone sources, it was successfully demonstrated that CT-121 maintains its excellent performance essentially independent of limestone and coal sources and, as a result, that the CT-121 process is adaptable to many new construction or retrofit scenarios.

An unexpected finding of the demonstration project was the impact of limestone selection on gypsum particle size and dewatering characteristics. Because the first limestone evaluated resulted in smaller-than-expected gypsum particle size and poor dewatering characteristics, a bench-scale evaluation of limestone source effects on gypsum size and dewatering was begun. While most of the limestones were very high in purity (typically >95% calcium carbonate), inert content and iron concentration in the limestone appeared to correlate with gypsum quality, with higher inert and iron levels resulting in poorer gypsum quality.

In general, above average gypsum byproduct quality was observed. During low-ash testing, the Dravo limestone produced gypsum that filtered and settled well, and had a mean particle size of 43 microns. The gypsum stack, a gravity sedimentation process chosen for dewatering and storage of the byproduct solids, worked well during the low-ash test period, even with up to 40% ash in the byproduct solids.

The gypsum stacking method proved effective in the long term. Although chloride content was initially high in the stack due to the closed loop nature of the process, a year later the chloride concentration in the gypsum dropped to a level making it suitable for wallboard and cement applications.

The CT-121 proved to be easy to operate and forgiving. Even with plugged sparger tubes, high SO_2 removal efficiency was maintained by adjusting key process parameters. Inexperienced operators had little difficulty controlling the process and operator errors were easily corrected with few adverse impacts. The system responded quickly and smoothly to transient operating conditions, although some tuning of the control logic was performed to damp pH and JBR $\triangle$P response.

Gypsum stacking area under construction

Figure 1. SO_2 Removal Efficiency

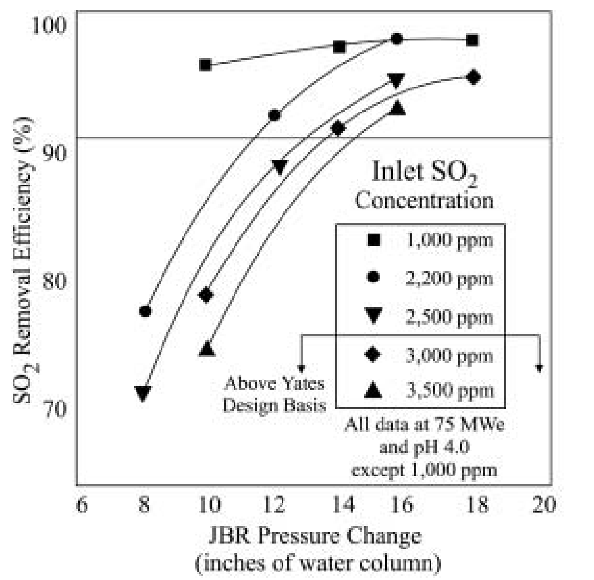
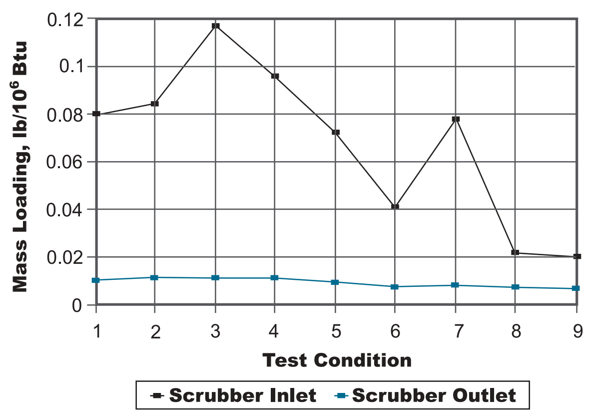


Figure 2. Low-Ash Loading – JBR Inlet and Outlet Average Particulate Mass Loading



Environmental Performance

SO_2 removal efficiency was evaluated throughout the CT-121 demonstration period. SO_2 removal efficiency was greater than 90% during all test periods.

SO_2 removal is dependent on slurry pH, JBR $\triangle$P, boiler load (gas flow rate), and inlet SO_2 concentration. SO_2 removal increases with increasing pH and JBR $\triangle$P and decreases with increasing load and inlet SO_2 concentration. Slurry pH and JBR $\triangle$P are the operational SO_2 control parameters. JBR $\triangle$P is the primary control parameter, affecting the gas/liquid interfacial area. SO_2 removal increases substantially as pH increases from 4.0 to 4.5, but there is little improvement when pH is further increased to 5.0. SO_2 removal decreases as load increases because the higher gas flows drive the JBR level lower for a given JBR $\triangle$P. Figure 1 shows SO_2 removal efficiency as a function of JBR $\triangle$P and inlet SO_2 concentration at 75 MWe and a pH of 4.0.

During both the low- and high-ash long-term, load following tests blocks, SO_2 removal was readily controlled to 94% (low-ash) and 93% (high-ash) set points using 2.5% sulfur baseline coal, producing an average 2,200 ppm SO_2 inlet concentration. All SO_2 values were presented on a dry basis, normalized to 3% oxygen. Some decrease in SO_2 removal was observed as a result of fouling of the sparger tubes, which occurred during high-ash testing. However, target performance levels were maintained by simply adjusting the pH or JBR $\triangle$P set points. Analysis showed that a 95% SO_2 removal set point could have been maintained. Auxiliary tests to evaluate maximum achievable SO_2 removal showed that the CT-121 can sustain removal efficiencies above 98% over a range of boiler loads using 2.5% sulfur baseline coal.

The data gathered during the various process operating conditions were used to develop performance models that could be used to characterize SO_2 removal efficiency as a function of several independent process variables. Multi-variable regression analyses were performed on these data and resulted in the development of several predictive performance models. A single comprehensive model was developed for the entire range of operating conditions, which had a goodness of fit (R2) of 0.935. Several models were also developed that covered a more limited range of operating conditions, having even higher R2 values. These predictive performance models served to: (1) permit comparison of the actual SO_2 removal efficiency to that predicted by the model, which was used to identify process problems, such as sparger tube plugging; and (2) determine the operating set points necessary to ensure that target SO_2 removal is achieved. These models can also be used as design tools in CT-121 commercial deployment.

Particulate removal efficiency was evaluated at three distinct ash loading levels during the demonstration: (1) low-particulate loading (ESP 100% energized), (2) moderate-particulate loading (approximately 90% ESP efficiency), and (3) high-particulate loading (ESP completely de-energized). During all three particulate removal tests, particulate removal efficiency was measured above 97%, and usually in excess of 99%.

As shown in Figure 2, low-ash loading ranged from 0.02–0.12 lb/10^6 Btu and the CT-121 reduced the particulate matter mass load to approximately 0.01 lb/10^6 Btu despite wide variation in the inlet loading.

As shown in Table 1, moderate-particulate loading, which represents a marginally operating ESP, produced similar results to the low-ash loading. The CT-121 reduced particulate matter to emission rates well below New Source Performance Standards (NSPS) of 0.03 lb/10^6 Btu for units constructed after September 18, 1978, and far below the Plant Yates permitted emissions rate of 0.24 lb/10^6 Btu.

As shown in Table 2, the CT-121 provided consistently high-particulate capture efficiency under high loading, but resulted in an average emission rate of 0.045 lb/10^6 Btu, which is above NSPS. Additional testing showed that at inlet loadings above 6 lb/10^6 Btu the CT-121 started to become overwhelmed, with outlet emissions rising in direct proportion to inlet loading.

Analysis indicated that 20% of the outlet mass loading was sulfate or sulfuric acid mist, with the majority being sulfuric acid mist resulting from SO_3 condensing in the CT-121.

For particulate sizes greater than 2 microns, capture efficiency was consistently greater than 99%. A dramatic reduction in particulate removal efficiency occurred between 0.6 and 1.0 microns, with capture efficiency at 1.0 micron approximately 82%. There appeared to be no removal of particulate in the 0.3–0.6 micron size range, but removal picked up again below 0.3 microns to approximately 90%.

Two test programs measured toxic air pollutant removable efficiency during the demonstration. One program was a DOE-sponsored test and the other, which focused on inorganic toxics, was done in conjunction with the moderate-ash particulate removal measurements. The data collected indicate that the JBR captured: (1) more than 99% and 98% of the hydrochloric and hydroflouric acid gases, respectively; (2) 84% - 96% of most trace metals, including arsenic (92.7%) and lead (96.7%); approximately 46% of mercury and cadmium; and 67% of selenium.

In 1996, Georgia Power received a Plant Food Permit from the State of Georgia that allows the unrestricted sale of ash-free gypsum from the Yates project for agricultural purposes. This market exceeds one million tons per year in Georgia alone.

Table 1. CT-121 Particulate Capture Performance (ESP Marginally Operating)

JBR Pressure Change (inches of water column)	Boiler Load (MWe)	Inlet Mass Loading (lb/10^6 Btu)	Outlet Mass Loading* (lb/10^6 Btu)	Removal Efficiency (%)
18	100	1.288	0.02	97.7
10	100	1.392	0.010	99.3
18	50	0.325	0.005	98.5
10	50	0.303	0.006	98.0

*Federal NSPS is 0.03 lb/10^6 Btu for units constructed after September 18, 1978. Plant Yates permit limit is 0.24 lb/10^6 Btu as an existing unit.

Table 2. High-Ash Loading – JBR Inlet and Outlet Average Particulate Mass Loading

Condition	Average Inlet, lb/10^6 Btu	Average Outlet, lb/10^6 Btu	Part. Removal Efficiency, Percent
100 MW ESP off	5.778	0.049	99.14
100 MW ESP off	5.293	0.042	99.21
50 MW ESP off	5.046	0.056	98.88
50 MW ESP off	4.927	0.048	99.02

Economic Performance

The capital cost of the 100 MWe Plant Yates project was \$29,335,979, or \$293/kW, including equipment, total construction costs of all associated processing and generating systems, and start-up costs. The annual fixed O&M cost was \$357,000 per year (1994\$). Variable operating cost was \$34 - \$64/ton of SO_2 removed (1994\$), depending on specific test conditions. Projected capital costs for commercial implementation of a FRP constructed CT-121 process are in the range of \$80 - \$95/kW. Levelized cost estimates are not available.

Capital costs are low because FRP construction eliminates the need for prescrubbing and reheating flue gas and high system availability eliminates the need for a spare absorber module. Particulate removal capability eliminates the need for expensive (capital-intensive) ESP upgrades to meet increasingly strict environmental regulations.

Extensive greenhouse and field agronomic evaluations concluded that the CT-121 gypsum is a high-quality material, similar to or better than currently marketed gypsum agricultural materials. It is suitable as a soil amendment for peanuts and other crops. For these reasons a plant food license has been obtained from the Georgia Department of Agriculture for food crop soil amendments. The market for the gypsum in Georgia alone is over one million tons per year.

Studies showed that both CT-121 process gypsum and fly ash should be marketable for forage production based on multi-year yield responses. Even marginal annual increases in crop yield resulted in a significant return on CT-121 gypsum and fly ash application over several years. Equivalent values of greater than \$100 per ton (1994\$) for the material over a five year period were considered fairly conservative. Other sources of gypsum were priced considerably higher. Mined gypsum available in southern Georgia was \$100 - \$140/ton (1994\$).

Long-term storage of stacked CT-121 gypsum resulted in chloride removal through leaching of the stack, making the gypsum marketable for wallboard and cement production.

Commercial Applications

A large number of domestic coal-fired power generators fuel switched instead of installing scrubbers to meet SO_2 reduction requirements under the Clean Air Act Amendments of 1990. However, revised National Ambient Air Quality Standards (NAAQS) issued in 1997 set new standards for concentrations of particulate matter in the respirable range of 2.5 microns or less ($PM_{2.5}$), which begins to take effect in 2007. The revised NAAQS impacts on SO_2 emissions because SO_2 forms $PM_{2.5}$ particulate matter, such as sulfates, after leaving the stack. Scrubbers are the most likely option to meet the stringent $PM_{2.5}$ regulatory requirements. Also, mercury emissions are to be regulated by 2005 and are projected to be implemented by 2007. These regulatory factors make CT-121 a strong candidate in the arsenal of compliance options to be considered in meeting tough new emission requirements. CT-121 not only offers high sulfur capture efficiency, but augments fly ash-based $PM_{2.5}$ capture and control of mercury emissions. Moreover, studies suggest that application of selective catalytic reduction (SCR) for NO_x control prior to scrubbing oxidizes the mercury and enhances mercury capture. SCR is being applied to existing coal-fired capacity at an ever increasing rate to meet tightened NO_x emission standards. CT-121 has application to approximately 300 gigawatts of existing coal-fired capacity.

The CT-121 system has been applied in a number of countries on different fuels and at many different sizes, ranging up to 750 MW in a single module. As of this publication, over 8,200 MWe equivalent of CT-121 FGD capacity has been sold to 17 customers in 8 countries since the demonstration. Another 5 projects are either in design or under construction. Plant Yates continues to operate the CT-121 scrubber as an integral part of the site's environmental compliance strategy.

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