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Project Summary

Pilot-Scale Parametric Testing of Spray Dryer SO_2 Scrubber for Low-to-Moderate Sulfur Coal Utility Applications

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A comprehensive dry SO_2 scrubbing test program was conducted which involved an in-depth field pilot study at the Comanche Station of Public Service Company of Colorado. The program investigated the effects of a number of process variables on SO_2 removal. The ranges of process variables tested during the program were: inlet flue gas SO_2 concentration, 185-2150 ppm; stoichiometric ratio, 0.5-6.4 moles lime/mole SO_2; recycle ratio, 0-4.3 lb* recycle solids/lb fresh lime; inlet flue gas temperature, 226-340°F; spray dryer flue gas outlet temperature, 128-210°F; and fabric filter temperature, 117-200°F.

In the spray dryer, stoichiometric ratio, flue gas temperature approach to adiabatic saturation, and temperature drop across the spray dryer significantly influenced SO_2 removal. In the fabric filter, stoichiometric ratio and temperature approach to adiabatic saturation controlled SO_2 removal. Recycling of flue gas desulfurization (FGD)/flyash product solids enhanced SO_2 removal over that of lime-only once-through operation. In the absence of fresh lime, recycle solids, and flyash solids in separate tests each produced about 20 percent SO_2 removal at a stoichiometry of 1 mole alkali/mole SO_2. Over the range investigated (30 to over 90 percent), SO_2 removal correlated well with the key spray dryer and fabric filter process parameters.

The final phase of the field test program consisted of a continuous demonstration of dry SO_2 scrubbing technology. The 5-day continuous run demonstrated that the spray dryer/fabric filter system can achieve the 70 percent SO_2 removal level required to meet the New Source Performance Standards for low sulfur coal.

Pilot test results related to stoichiometry, recycle ratio, and unit operating temperatures provided the basis for a technoeconomic evaluation that showed that a spray dryer SO_2 removal system is less costly than limestone wet FGD/particulate control systems (fabric filter/limestone scrubber, ESP/limestone scrubber) for coal sulfur levels up to about 1.5-1.8 wt percent.

Dry SO_2 scrubbing solid waste characteristics also were evaluated. Spray dryer product solids are coarser than fabric filter solids (30-35 μm versus about 10 μm mean diameter). Product solids chemical compositions from the two sources are similar, but spray dryer solids contain higher concentrations of unused reagent and fabric filter solids contain increased percentages of FGD products. Curing for 1 month at 72°F and about 100 percent relative humidity increased the cohesive strength of the waste solids by a factor of 3-6. Product solids leachate heavy metal contents are significantly less than hazardous waste maximum allowable levels.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of

* EPA policy is to express all measurements in Agency documents in metric units. This project summary uses English units to improve clarity of presentation. Conversion factors are provided at the end of this summary.

the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Dry SO_2 scrubbing has emerged as a new technology and appears to be a cost-effective desulfurization process for low-sulfur western coals. Contracts for at least 10 first generation dry scrubbing systems already have been awarded, and many additional projects are being evaluated. The attractiveness of the dry SO_2 scrubbing system compared to wet FGD lies in its physical simplicity, moderate pressure drop, very low water use, reduced reheat requirements, and the dry condition of the reduced volume of waste solids produced.

The first example in the U.S. of dry SO_2 scrubber testing using a spray dryer for utility coal-fired boiler application occurred in the early 1970s. A spray dryer was used to remove SO_2 with an aqueous sodium carbonate reagent. However, major spray dryer SO_2 scrubbing test activity began only as recently as 1977. At this time, several companies participated in spray drying and baghouse pilot testing at the Leland Olds Station of Basic Electric Power Cooperative. Sodium reagents were tested initially, but potential disposal problems and high costs turned the investigations toward other alkaline compounds. Additional testing indicated that slaked lime held the most promise as an economical reagent for dry SO_2 scrubbing.

Pilot tests at the Hoot Lake Station of Otter Tail Power Company demonstrated greater than 90 percent overall SO_2 removal at a stoichiometric ratio of: 2.0-3.0 moles lime/mole SO_2, using lime-only operation; and 1.0-1.5 moles lime/mole SO_2, with recycle. The study also identified the importance of operating the spray dryer near the adiabatic saturation temperature to enhance SO_2 removal. The Hoot Lake results also showed that an alkaline flyash, especially under recycle operation, contributes significantly to SO_2 removal.

Field and laboratory pilot tests utilizing a horizontal flow reactor and dual fluid atomization identified several variables that affect SO_2 removal. They include stoichiometry, approach to adiabatic saturation temperature, inlet gas temperature to the system, and flyash alkalinity. Lime stoichiometry was the primary correlating variable with SO_2 removal, but flyash alkalinity also played a strong role. SO_2 removal using flyash alone was 15-65 percent with highly alkaline Laramie River flyash.

In 1981-82, parametric pilot tests at the Martin Drake Station of the City of Colorado Springs showed the importance of operating near the adiabatic saturation temperature on SO_2 removal, but found that inlet gas temperature to the spray dryer had a negligible effect. Using lime-only operation, SO_2 removal was considerably reduced at 2000 and 2500 ppm inlet SO_2 concentrations from that at 1000 and 1500 ppm SO_2. Fabric filter SO_2 removal in the Martin Drake tests was strongly affected by the approach to adiabatic saturation temperature and was also a function of stoichiometric ratio.

The present program examines the systematic application of dry SO_2 scrubbing technology to treat utility flue gas using a spray dryer and fabric filter. A pilot test program at the Comanche Station of Public Service Company of Colorado investigates the effect of key process variables and recycled solids on SO_2 removal. Study of the fabric filter variables on SO_2 removal is confined to the effects that occur simultaneously with the testing of the spray dryer. Also, the present investigation does not address the efficiency of particulate removal in the dry scrubbing system.

The final phase of the field test program is a continuous demonstration of spray dryer/fabric filter technology. The demonstration run is to verify that SO_2 removal can be achieved on a sustained basis to meet the New Source Performance Standards (NSPS) for utility boilers operating on flue gas generated from low sulfur fuels. Field test results are utilized in a techno-economic evaluation to establish the areas where dry FGD technology may be applied economically.

The characteristics of the solid wastes produced from the dry SO_2 scrubbing system are also evaluated. Materials generated at the pilot test site are examined at the CES laboratory facilities. This limited scope program of testing and evaluation is to determine 1) the basic composition of the waste products, and 2) the soil-mechanical and leaching properties of the FGD solids/flyash mixtures, to determine their suitability for landfill disposal or reuse. Solid samples are also analyzed for trace heavy metals to provide hazardous waste information.

Pilot System Description

The pilot test system, Figure 1, is designed to treat up to 10,000 acfm (nominal) of flue gas. The system consists of a spray dryer to remove SO_2 followed by a fabric filter to collect dry FGD solids and flyash. An induced draft fan moves the flue gas through the system and a second "reverse air" fan is used to clean the fabric filter. Feed tanks and metering pumps supply reagent to the system. An SO_2 tank and delivery system provide additional SO_2 to the flue gas for tests at higher inlet flue gas SO_2 concentrations.

Spray Dryer

The pilot spray dryer is 8 ft in diameter, 35 ft high, and equipped with a variable-speed rotary-disc atomizer. The atomizer used in this program has a titanium body disc with silicon carbide ports around the periphery. The bottom plate of the disc is coated with aluminum oxide for protection against slurry abrasion.

Dirty flue gas containng SO_2 and flyash enters the top of the spray dryer where it is intimately contacted with finely atomized lime slurry. The intimate contact and large

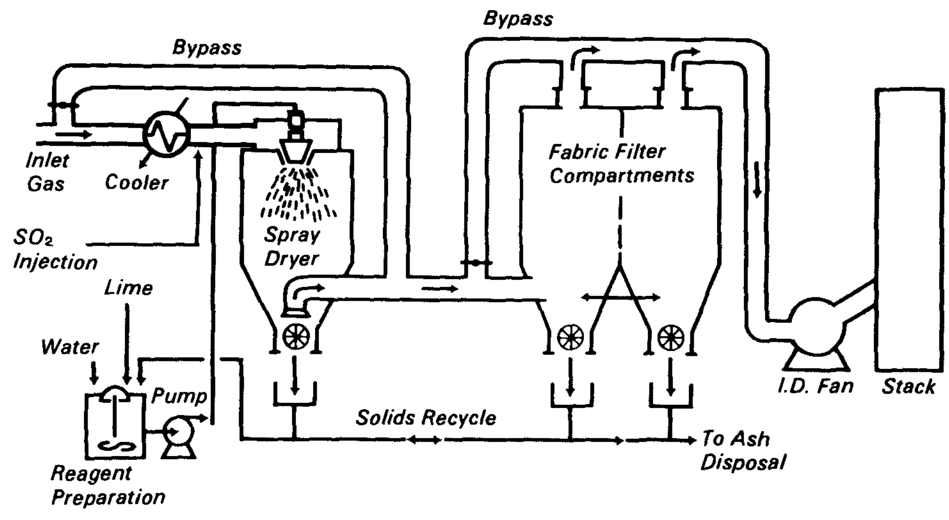

Figure 1. *Dry SO_2 scrubbing pilot flow schematic.*

interfacial area of the spray dryer result in very rapid SO_2 absorption by the lime slurry. Most of the SO_2 removal in the overall system occurs in the spray dryer. Before leaving the dryer, the solids approach complete dryness. In the pilot unit, coarse solids settle in the conical bottom of the dryer and are discharged through a rotary valve to receiving drums. The scrubbed flue gas containing finer particles leaves the dryer through a side port and flows to the fabric filter.

Fabric Filter

The fabric filter is 10 x 15 x 55 ft and is operated with two compartments each designed to process about 5,000 cfm of flue gas. Commercial Teflon-coated fiberglass bags were used in the fabric filter. Each fabric filter bag is 12 in. in diameter, 30 ft high, and contains about 94 ft^2 of bag surface. Twenty to 24 bags (10 to 12 per compartment) were used in various tests during the pilot program.

In the fabric filter, flyash and FGD solid particulate are removed from the flue gas and additional SO_2 is removed. From the fabric filter, the flue gas flows to the induced draft fan and then to the stack. Flue gas from the spray dryer continuously enters the bottom of the fabric filter unit and leaves from the top.

To limit pressure drop across the filter bags from the accumulation of collected solids, a flow of air periodically is passed through the bags in the reverse direction for a short period of time (1 to 2 min/hr). The "reverse air" flow dislodges most of the deposited solids from the bag surface; they drop into the collection hoppers, from where they are discharged through rotary valves. During the brief bag cleaning period, flue gas is bypassed around the fabric filter. Valves are operated from the control room either manually or automatically.

Pilot Test Program

The pilot test program consists of process variable parametric studies and two continuous process demonstration runs (one short- and the other long-term).

Process Variable Tests

The process variable tests were empirical investigations designed primarily to identify the dominant variables that affect SO_2 removal and to establish their relative importance, rather than to determine why they are important or the underlying mechanisms involved. The parametric studies were carried out using two operating modes: (1) process variable tests using lime reagent in once-through operation with no product solids recycle; and (2) process variable tests incorporating recycled solids.

The process variables considered relevant to SO_2 removal were studied over the ranges of conditions shown in Table 1.

Short-Term Process Demonstration

A continuous process demonstration run was conducted to verify that SO_2 removal levels can be achieved on a sustained basis to meet New Source Performance Standards. Specific operating conditions for the demonstration were selected, based on results of the process variable tests. Dry scrubbing system operability and control as well as SO_2 performance were observed over the course of the run.

Conclusions of Major Process Variable Studies

Spray Dryer SO_2 Removal

1. Parameters that dominate spray dryer SO_2 removal performance are: stoichiometric ratio, SR; approach to adiabatic saturation temperature, $\Delta T_{AS/SD}$: temperature drop across the spray dryer, ΔT_{SD}; and recycle ratio, RR.
2. Spray dryer SO_2 removal increases directly with fresh lime stoichiometry. At lower stoichiometries, SO_2 removal in the spray dryer is quite sensitive to stoichiometric ratio. At higher stoichiometries, SO_2 removal levels off and stoichiometric ratio has much less effect on spray dryer SO_2 removal.
3. SO_2 removal efficiency in the spray dryer increases as the flue gas temperature approaches the adiabatic saturation temperature.
4. SO_2 removal in the spray dryer increases as the temperature drop across the spray dryer is increased. Spray dryer temperature drop directly reflects the liquid-to-gas ratio and the quantity of water fed to the dryer.
5. Spray dryer solids moisture content increases as the flue gas temperature approaches the adiabatic saturation temperature.
6. The optimum spray dryer operating temperature strikes a balance between high SO_2 removal and smooth trouble-free discharge and handling of moisture-laden product solids.
7. Spray dryer SO_2 removal is enhanced as the amount of recycle material (recycle ratio) increases. SO_2 removal increases as recycle ratio increases up to a value of about 2.5 lb recycle solids/lb fresh lime, where it levels off, indicating no further benefit to recycling additional solids.
8. Spray dryer flue gas residence time of 8-16 sec and spray dryer inlet SO_2 concentration of 185-2150 ppm have very little effect on SO_2 removal.

Fabric Filter SO_2 Removal

1. The process parameters that significantly affect fabric filter SO_2 removal are: stoichiometric ratio, approach to adiabatic saturation temperature, and recycle ratio.
2. SO_2 removal in the fabric filter increases proportionately with increasing fresh lime stoichiometry.
3. SO_2 removal in the fabric filter increases as the flue gas temperature approaches the adiabatic saturation temperature.
4. Product solids recycle enhances SO_2 removal across the fabric filter.
5. Air-to-cloth ratio and fabric filter inlet SO_2 concentration have negligible effects on SO_2 removal in the fabric filter.

Overall SO_2 Removal

1. The dry scrubbing system can attain the 70-90 percent (see main report) SO_2 removal required by the New Source Performance Standards (NSPS). Lime stoichiometry is minimized by operating with recycle at high flue gas inlet temperature to the spray dryer, low spray dryer outlet temperature, and low fabric filter inlet temperature.

Table 1. *Range of Pilot Test Variables*

Variable	*Minimum*	*Maximum*
Stoichiometric Ratio, moles $Ca(OH)_2$/mole SO_2 in	*0.5*	*6.4*
SD Inlet Flue Gas Temperature, °F	*226*	*340*
SD Outlet Flue Gas Temperature, °F	*128*	*210*
Fabric Filter Gas Temperature, °F	*117*	*200*
Inlet SO_2 Concentration, ppmv	*185*	*2,150*
Atomizer Disc Diameter, in.	*7⅝*	*8½*
Atomizer Disc Speed, rpm	*10,600*	*13,920*
Inlet Flue Gas Rate, acfm	*3,000*	*7,500*
Fabric Filter Air-to-Cloth Ratio, ft/min.	*1.3*	*2.8*
Lime Slurry Feed Concentration, wt %	*3*	*25*
Recycle Slurry Solids Concentration, wt %	*10*	*53*
Recycle Ratio, lb recycle solids/lb fresh lime	*0*	*4.3*

2. The spray dryer is the primary SO_2 control unit in the system. The fabric filter is the primary particulate control unit. In the present study, more than 75 percent of the total SO_2 was removed in the spray dryer, and considerably more than half of the total solids were collected in the fabric filter.

Long-Term Process Demonstration

A 5-day, 120-hour, continuous process demonstration run was successfully conducted without interruption and with negligible operating problems.

The continuous run demonstrated that the spray dryer/fabric filter system can achieve the 70 percent SO_2 removal level required to meet the New Source Performance Standards for low sulfur coal (Figure 2).

Waste Characterization Studies

As part of the dry SO_2 scrubbing test program, a brief study was undertaken to characterize the solids wastes produced by the spray dryer/fabric filter dry scrubbing process. Only a modest amount of information has been published at the present time on the nature of the waste solids or their disposal characteristics.

The FGD solids/flyash samples were collected at the Comanche test site during the pilot runs and sent to CES laboratory facilities for the characterization. To generate the samples, the pilot unit was operated steady-state at carefully chosen levels of stoichiometry and atomization until about 100 lb of representative waste was collected.

A wide spectrum of operating conditions is represented in the runs sampled. The operating conditions for each run in which samples were taken are summarized in Table 2. In most cases, a blend of 70 percent baghouse solids and 30 percent spray dryer solids (by weight) was tested. The 70/30 split is normal for typical operating conditions, such as those given in Table 3. In three cases, only fabric filter solids were tested; in one other run, only spray dryer solids were evaluated.

Conclusions of Waste Characterization

1. Optimum compacted densities of 78-90 lb/ft^3 are obtained at dry waste solids moisture contents of 25-35 wt percent H_2O. Dry scrubbing waste product compacted densities are lower, and corresponding moisture contents are higher than values reported for sludge/flyash blends from wet FGD systems (115-120 lb/ft^3 and 15-20 wt percent H_2O).
2. The cohesive strength and angle of internal friction of waste products from the lime-only runs are 40-50 percent greater than for the waste products from recycle runs. Cohesive strength increases 3- to 10-fold and angle of internal friction increases 30-50 percent upon curing of waste solids for approximately 1 month at 72°F and about 100 percent relative humidity (Table 3).
3. Permeability values for uncured dry scrubbing product solids are of the order of 10^{-5} cm/sec. For samples cured approximately 1 month at 72°F and 100 percent relative humidity, permeability is 10^{-6}-10^{-7} cm/sec (Table 3).
4. The total dissolved solids content of the leachate from the dry scrubbing waste products generally exceeds 1200 ppm; most of it is attributable to $CaSO_4$.

Technoeconomic Study

A technoeconomic study was performed to compare a dry SO_2 scrubbing system using lime reagent with wet FGD systems using limestone. The SO_2/particulate pollution control systems evaluated in this study in-

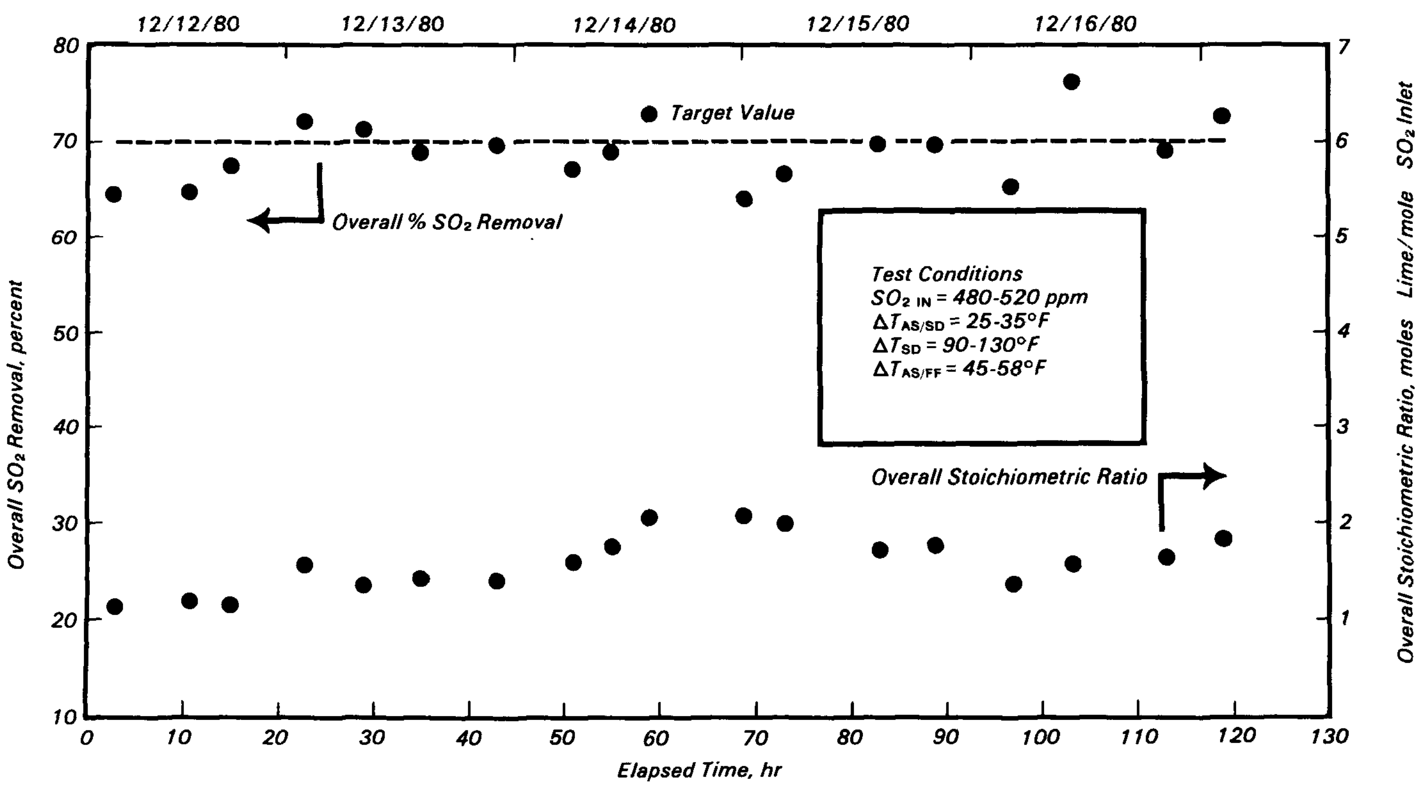

Figure 2. *Process demonstration test results—overall SO_2 removal and overall stoichiometric ratio.*

cluded: a spray dryer followed by a fabric filter (SD/FF), a fabric filter followed by a single-loop wet scrubber (FF/LS), and an electrostatic precipitator followed by a single-loop wet scrubber (ESP/LS).

Capital investment and annual operating costs were estimated and compared for the three pollution control systems studied. In addition, sensitivity analysis clarified the effect of system size (MW) and percent S in the coal on unit capital and unit operating costs. The effects of percent S in the coal and reagent price on lime reagent costs were also determined.

Study Design Basis

For the technoeconomic studies, a power plant in Colorado was used as the basis since the pilot test work was performed at the Comanche Station of Public Service of Colorado in Pueblo. The Powder River Basin coal used in this study had a heating value of 8230 Btu/lb and contained 0.6 percent sulfur, 5.77 percent ash, and 30.5 percent water. The SO_2 and particulate removal efficiencies were based on New Source Performance Standards of 0.6 lb $SO_2/10^6$ Btu and 0.03 lb particulate/10^6 Btu. The system design basis specified for these conditions is presented in Table 4.

Economic Basis

The technoeconomic comparisons were based on estimates of capital and operating costs for the three SO_2/particulate control systems. Capital costs include direct, indirect, and contingency costs, but not such charges as allowance for system start-up and modification, interest for system construction, land, working capital, and royalties. The capital cost estimates for the spray dryer, fabric filter, and electrostatic precipitator are based on Research-Cottrell cost estimate information. Capital cost estimates for the limestone scrubber are based on TVA values. Operating costs, including direct and indirect costs, are presented as first-year annual revenue requirements. Capital and operating cost estimates are calculated based on first-quarter 1981 dollars.

Equipment included in each pollution control system was divided into functional areas for cost estimating purposes. The direct cost of each area was estimated independently. The total direct investment for each system is the sum of the six process area direct costs. Indirect investment was assumed to be 30 percent of the total direct system investment. Contingency costs were of the sum of direct and indirect costs.

Capital Cost Estimates

Comparison of the total capital investment costs for the three SO_2/particulate pollution control systems shows that the dry scrubbing system is less costly than the two wet FGD systems. Table 5 shows that the total capital investment for a 500 NW spray dryer/fabric filter system treating flue gas generated from 0.6 percent S coal is

Table 2. *Operating Conditions for Pilot Plant Runs Chosen for Waste Characterization Sampling*

Run No.	Sample Source	Inlet SO_2 Concentration ppmv	Overall SO_2 Removal %	Stoichiometric Ratio moles lime/moles SO_2 in	Recycle Ratio lb recycle solids/lb makeup lime	Spray Dryer Temperature In-let °F	Spray Dryer Temperature Out-let °F	$\Delta T_{AS/SD}$ °F	Spray Dryer Residence Time sec
220	Blend	1350	39.4	3.01	0	268	188	71	10.0
314	Blend	1900	37.1	2.16	0	264	183	68	10.2
317	Blend	2150	43.1	1.05	0	345	185	70	10.4
405R2	Fabric Filter	760	59.3	1.07	2.27	340	180	50	10.2
506	Fabric Filter	850	50.9	2.01	0	258	178	48	9.5
624	Blend	780	39.9	1.04	1.06	295	177	48	9.9
923	Spray Dryer	1380	72.2	1.14	2.62	255	147	22	9.4
923	Fabric Filter	1380	72.2	1.14	2.62	255	147	22	9.4
923	Blend	1380	72.2	1.14	2.62	255	147	22	9.4

Table 3. *Product Solids Triaxial Compression and Permeability Test Results*

			Uncured		Cured[a]		Permeability	
Run No.	Operation Mode	Sample Source	Cohesion psi	Angle of Internal Friction degrees	Cohesion psi	Angle of Internal Friction degrees	Uncured cm/sec	Cured cm/sec
220	Lime-Only	Blend[b]	16.3	36	—	—	0.3×10^{-5}	—
314	Lime-Only	Blend	18.2	39	110	51	0.4×10^{-5}	3.5×10^{-6}[c]
317	Lime-Only	Blend	15.8	37	—	—	1.2×10^{-5}	—
405-R2	Recycle	Fabric Filter	6.0	33	63	51	0.2×10^{-5}	3.5×10^{-6}[d]
506	Lime-Only	Fabric Filter	14.0	34	63	48.5	3.3×10^{-5}	0.7×10^{-6}[a]
624	Recycle	Blend	13.0	32.5	34	42	8.9×10^{-5}	0.9×10^{-6}[a]
923	Recycle	Spray Dryer	12.0	24	—	—	7.1×10^{-5}	—
923	Recycle	Fabric Filter	12.1	21	—	—	9.3×10^{-5}	—
923	Recycle	Blend	10.2	22	—	—	5.3×10^{-5}	—

[a] Cured for 28 days at 72°F and about 100 percent relative humidity.
[b] Blend refers to a physical mixture of 70 wt percent fabric filter solids and 30 wt percent spray dryer solids.
[c] Cured for 35 days at 72°F and about 100 percent relative humidity.
[d] Cured for 38 days at 72°F and about 100 percent relative humdity.

estimated at $42,300,000. The fabric filter/limestone scrubber system cost estimate is $59,046,000. The ESP/limestone scrubber system cost estimate is $63,699,000.

The conclusions on capital investment reached during the study are similar to those presented by a TVA study. In each study, the total fixed capital investment for the dry scrubbing system is about 30 percent less than for an ESP/limestone scrubber system. However, the fixed capital investment figures developed in the present study are 15-20 percent less than the corresponding TVA estimates. A significant part of the difference arises because the capital investment estimates of the present study are based on actual first-quarter 1981 dollars while the TVA study uses projected mid-1982 dollars. In view of the ±30 percent error range associated with study or preliminary estimates, the capital investment costs generated for these and the TVA evaluations agree fairly well.

These cost estimates show that dry system costs are 30-35 percent lower than wet FGD/particulate systems costs for low sulfur coal applications. Unit costs for the three systems at a 500 MW size are $84.6/kW for the spray dryer/fabric filter, $118.1/kW for the fabric filter/limestone scrubber, and $127.4/kW for the ESP/limestone scrubber case.

Table 4. *Study Design Basis*

Item	Design Value
Flue Gas Rate, acfm	2,040,000
SO_2 Inlet Concentration, ppm	600
Flue Gas Inlet Temperature, °F	275
Atmospheric Pressure, psi	12.3
SO_2 Removal Efficiency, %	70
Particulate Inlet Content, gr/acf	2.3
Particulate Removal Efficiency, %	99.7

Table 5. *Comparison of System Total Capital Investments (500 MW, 0.6% S Coal, 70% SO_2 Removal)*

Investment Area	Total Cost, 1000$ (1981$) Lime Spray Dryer/ Fabric Filter	Fabric Filter/ Limestone Scrubber	Electrostatic Precipitator/ Limestone Scrubber
Material Handling	3,391	800	800
Feed Preparation	850	1,100	1,100
Gas Handling	5,975	8,554	8,554
SO_2 Absorption	7,145	11,802	11,802
Particulate Removal	9,230	10,990	13,973
Waste Disposal	524	4,604	4,604
Total Direct Investment	27,115	37,850	40,833
Indirect Investment	8,135	11,355	12,250
Contingency	7,050	9,841	10,616
Total Fixed Investment	42,300	59,046	63,699
Unit Cost ($/kW)	84.6	118.1	127.4

Table 6. *Comparison of System Annual Operating Costs (500 MW, 0.6% S Coal, 70% SO_2 Removal, 7000 hr/yr Operation)*

Item	Total Cost, 1000$ (1981$) Lime Spray Dryer Fabric Filter	Fabric Filter/ Limestone Scrubber	Electrostatic Precipitator/ Limestone Scrubber
Raw Materials	1,026	225	225
Electricity	1,820	2,282	2,487
Water	40	73	73
Maintenance	1,654	3,217	3,062
Operating Labor	649	774	749
Overhead	832	1,269	1,274
Administration	65	77	75
Capital Charges	6,345	8,857	9,555
Total Cost, 1000$	12,431	16,774	17,500
Unit Cost, mills/kWh	3.6	4.8	5.0

Operating Cost Estimates

Annual operating costs (first-year annual revenues) were estimated for the three pollution control cases for a 500 MW power plant burning 0.6 wt percent S coal and operating 7000 hr/yr. Cost comparisons in Table 6 show that dry scrubbing system operating costs are about 25-30 percent lower than wet FGD/particulate control systems costs under the conditions investigated. All operating cost items except raw materials, or reagent, costs are less for the dry scrubber system. Reagent costs are much higher for dry scrubbing than for wet scrubbing primarily because of the large cost differential between lime and limestone, $70 vs. $8/ton. Essentially all of the operating cost difference between dry and wet scrubbing systems determined in the present study is attributable to capital investment-related items, maintenance, and capital charges.

The results of the present study and those of TVA indicate that dry scrubbing annual operating costs are 25-30 percent less than ESP/limestone scrubber costs. Annual operating cost estimates of this study are only 70-75 percent of those developed by TVA. Much of the annual operating cost difference is attributable to lower capital charges used in the present study compared to the TVA work. Lower operating labor hourly rates and costs of this study also account for some of the operating cost difference.

Lime Reagent Cost

For the present study, lime reagent costs are somewhat more sensitive to increases in the coal sulfur content than to raw material price. Lime costs increase 5-7 times to meet the reagent requirements as coal sulfur increases from 0.6 to 1.5 wt percent. In this coal sulfur range, lime reagent costs (at a price of $70/ton) increase from less than 10 percent of the total operating costs at 0.6 percent to about 30 percent at 1.5 percent S. Since lime reagent cost is very sensitive to sulfur level, dry scrubbing enjoys its greatest economic advantage over wet FGD systems for low sulfur coal applications. As coal sulfur content increases, the cost difference between wet and dry systems decreases. The operating cost crossover point is estimated at somewhat greater than 1.5 percent S coal for the bases used in the present study (Figure 3). Note that the spray dryer/fabric filter operating cost increases more rapidly as the coal sulfur content increases. This is due to the greater lime requirement (higher stoichiometric ratios) as the sulfur content increases.

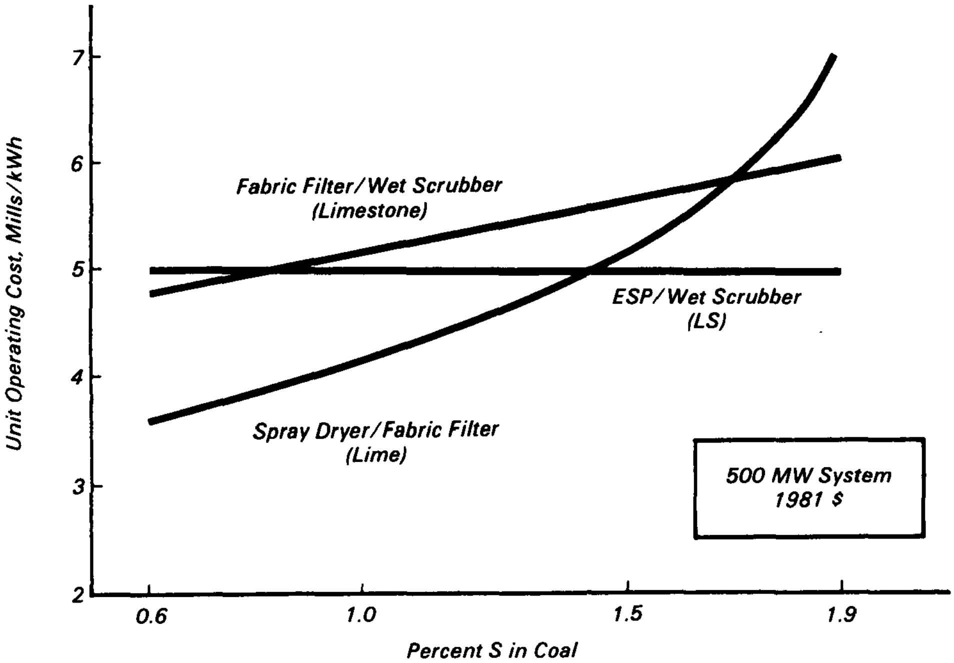

Figure 3. *Unit operating cost sensitivity.*

Conclusions of Technoeconomic Study

1. The capital investment required for a dry SO_2 scrubbing system (spray dryer/fabric filter) is 30-35 percent less than for either of the two wet FGD systems (fabric filter/limestone scrubber, ESP/limestone scrubber) based on estimates for a 500 MW unit burning Powder River Basin coal with 0.6 percent sulfur and complying with the NSPS.
2. Annual operating costs (first year annual revenues) for a dry SO_2 scrubbing system (spray dryer/fabric filter) are 25-30 percent lower than for either wet scrubbing system (fabric filter/limestone scrubber, ESP/limestone scrubber).
3. Reagent costs for a dry scrubbing system using lime are much higher than for wet scrubbing systems using limestone. Lime costs 4-5 times as much as limestone for SO_2 control of flue gas generated from 0.6 wt percent sulfur coal and is a major operating expense for dry scrubbing systems. Lime reagent cost is affected by coal sulfur content, stoichiometric ratio, and raw materials price.
4. Unit capital costs are only moderately sensitive to system size (MW) for all three systems and increase as coal sulfur content increases (see main report). Dry scrubbing system costs are more sensitive to coal sulfur content than are wet scrubbing system costs.
5. For each of the three desulfurization processes, unit operating costs decrease as system size (MW) increases but are not very sensitive to size. Unit operating costs increase as coal sulfur content increases because of increased reagent use. Dry scrubbing system operating costs are more sensitive to coal sulfur content than are wet scrubbing system operating costs because dry systems use more-expensive lime as the reagent.
6. As coal sulfur content increases, the cost advantage of a dry system over a wet system decreases. The crossover range is about 1.5-1.8 percent sulfur for the conditions used in this study.

Conversion Factors

To Convert From English	To SI	Multiply By
cfm	m^3/hr	1.70
ft	m	0.305
gr/scf	kg/m^3	0.00229
in.	m	0.0254
in. H_2O	Pa	249
lb	kg	0.454
gal.	m^3	3.79
gal./1000 ft^3	liters/m^3	0.13
Btu	joule	0.252
short ton	tonne	0.91
°F	°C	5/9(°F-32)

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The complete report, entitled "Pilot-Scale Parametric Testing of Spray Dryer SO_2 Scrubber for Low-to-Moderate Sulfur Coal Utility Applications," (Order No. PB 84-175 959; Cost: $22.00, subject to change) will be available only from:
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