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Project Summary

Field Evaluation of a Utility Dry Scrubbing System

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This program was the first independent evaluation of a full-scale utility spray-dryer/baghouse dry flue gas desulfurization (FGD) system. The evaluated system treats flue gas from a nominal 100 MW of coal-fired power generation.

For the test program, two different coals were used as boiler fuels: one, a subbituminous coal and coke mixture with a nominal 1.2 percent sulfur content; and the other, a 3.4 percent sulfur Illinois bituminous coal.

The test program was conducted from July to October 1983. SO_2 removal, particulate emissions, sulfuric acid removal, and extensive process data were recorded. Low sulfur coal tests indicated that 75 percent SO_2 removal was achievable in the short term at reagent ratios of 0.6 to 0.7, and 90 percent SO_2 removal was achievable at a reagent ratio of about 0.8. An average removal of nearly 90 percent was achieved in short-term tests with high sulfur coal at reagent ratios of 1.3 to 1.4. Calcium chloride addition to the atomizer feed slurry was found to reduce the lime addition requirements for high sulfur tests by about 25 percent.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Pack, 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

This Summary discusses results from a program, the objective of which has been to acquire performance data on an operating, utility-scale, spray-dryer-based, dry FGD system. The system was evaluated primarily to determine SO_2 and particulate removal performance and lime reagent consumption. The system chosen for evaluation is the Joy/Niro Demonstration Unit, at the Northern States Power Company (NSP) Riverside Station in Minneapolis, MN. The Riverside system was chosen for this program because it is the first lime-based system in operation using a full-size (46-ft* diameter) spray dryer module. Testing was conducted with both low and high sulfur boiler fuels. The program was conducted for the Environmental Protection Agency's Air and Energy Engineering Research Laboratory and for the Electric Power Research Institute under a cooperative funding arrangement.

Project Description

The project description includes that of the Riverside station and FGD system, a summary of the test program, and a discussion of the limitations of the Riverside system and how they have affected this evaluation.

Site Description

The Riverside generating station, operated by Northern States Power Company, in northeast Minneapolis. The two units of interest on this project, No. 6 and No. 7, began operation in 1949. The combined generating power of Units 6 and 7 is rated at 98 MW. However, the pulverized coal, wall-fired units were originally designed to fire an eastern bituminous coal. Recently, the units have fired a western (Sarpy Creek) subbituminous coal. A small amount (10 to 15 percent) of high sulfur coke is

*Readers more familiar with metric units may use the conversion table at the back of this Summary.

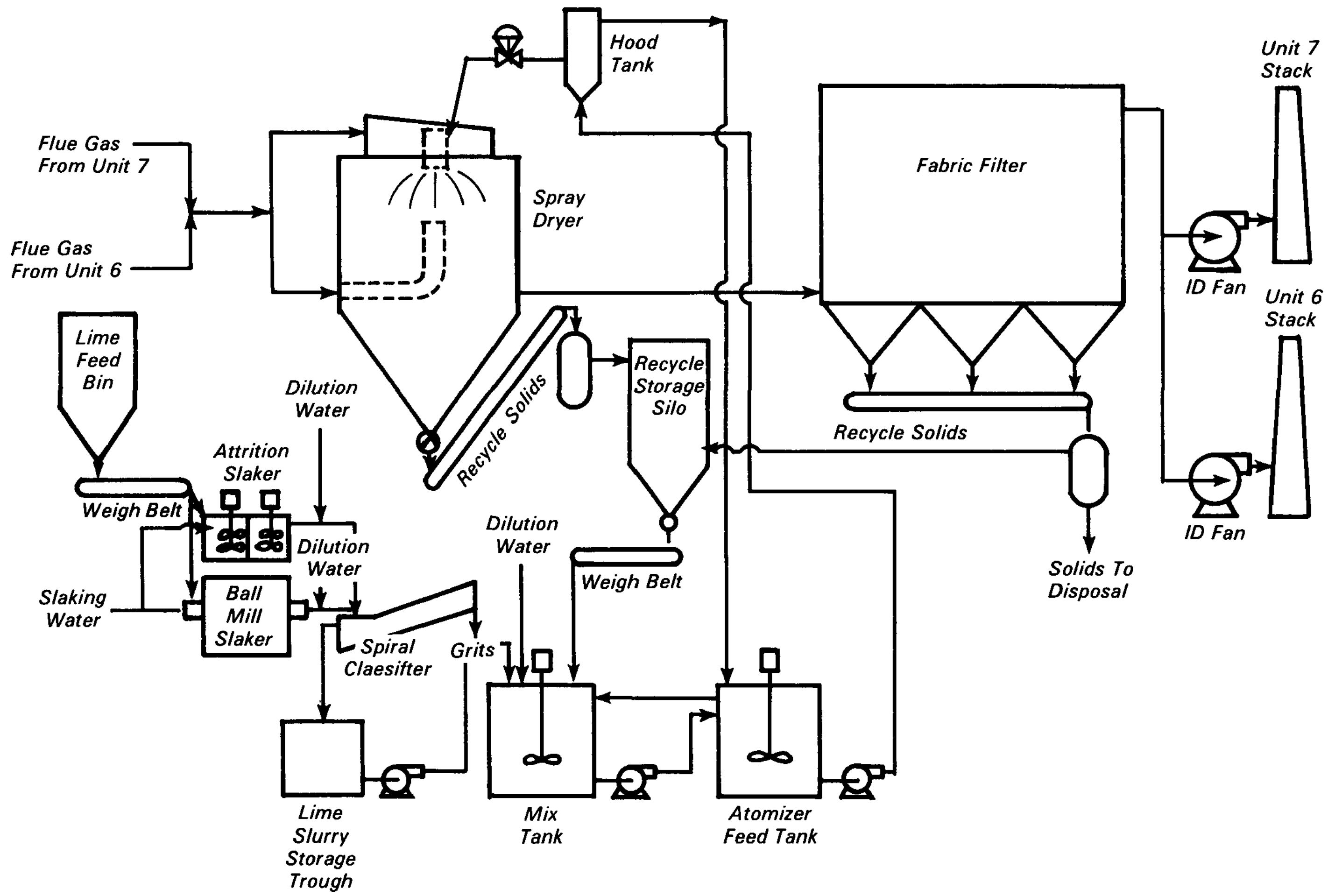

Figure 1. *Flow diagram for Riverside dry FGD system.*

added to the subbituminous coal to improve its firing properties. The units can still be fired with high sulfur bituminous coal, and in fact were so fueled for 5 weeks of this test program.

In 1980, a full-scale, Joy/Niro, spray-dryer/fabric-filter FGD system was installed to treat the combined flue gas from the two units. The fabric filter was actually purchased by NSP because of limitations on the ability of existing ESP collectors to efficiently collect the ash from the western coal. The spray dryer system was installed by Joy/Niro under a cooperative agreement with the utility to serve as a full-scale demonstration of the capabilities of their dry FGD system. Figure 1 is a simplified flow diagram of the system.

The spray dryer is 46 ft in diameter, with flue gas introduced both above the atomized spray in a roof gas disperser and below the atomized spray in a central gas disperser. A rotary atomizer is used, employing a 700 hp drive motor. The spray dryer was sized to treat flue gas corresponding to a 70 MW boiler load. This reduced sizing permitted system tests at greater than design flow rates. Note that, because Units 6 and 7 are over 30 years old, the flue gas flow rate at 70 MW is equivalent to the flue gas rate from about a 100 MW new unit. A new unit would experience much less air inleakage and operate at a much lower net plant heat rate than these units. The downstream fabric filter contains 12 compartments, in 2 rows of 6 compartments each. Because the fabric filter was sized to treat hot flue gas, it is actually oversized when the spray dryer is in operation because of the flue gas volume shrinkage which results from the reduced spray dryer outlet temperature.

Pebble lime reagent is slaked in a Joy/Denver attrition slaker. A Joy/Denver ball mill is also available for lime slaking. Milk of lime, dilution water, and recycle solids are added to a mix tank at rates determined by a Honeywell process control computer. The mix tank effluent is pumped to a separate atomizer feed tank. From the atomizer feed tank, slurry is pumped to a head tank at the top of the spray dryer. A pinch-type control valve regulates the flow of slurry to the atomizer to maintain either a constant spray dryer outlet temperature or a constant approach to adiabatic saturation. When the system is operated to control SO_2 removal, the Honeywell process control computer calculates the amount of lime which must be added upstream at the mix tank to achieve the desired SO_2 removal. Recycle material is added at the mix tank at a rate required to bring the mix tank solids level up to a set point, normally 35 weight percent solids. The recycle solids are collected from the spray dryer bottom dropout and largely supplemented by a portion of the fabric filter catch.

Testing Approach

As described in the introduction, a primary objective of the program was to quantify SO_2 removal by the system. A continuous emission monitoring system (CEMS) was temporarily installed to quantify SO_2 removal. The CEMS included a DuPont Model 460 two-point extractive SO_2 monitor and a Thermox O_2 monitor (sampling the spray dryer inlet and outlet ducts), and a Lear Siegler SM810 in-situ point-type SO_2 analyzer (installed in a short run of duct at the fabric filter outlet). A second Thermox O_2 analyzer was mounted on the duct exactly opposite the Lear Siegler monitor.

Other than SO_2 removal data, lime consumption and other important process parameters were recorded as hourly averages for each test day. Lime consumption was measured primarily by determining the lime content of the milk of lime slurry introduced to the atomizer feed mix tank. The flow rate of this slurry was continuously measured with a magnetic flow meter and recorded by the Honeywell process control system computer. Other methods of lime consumption measurement have included continuous quicklime weigh belt rate measurements, recording of daily quicklime truckload deliveries, and determination of the lime content and flow rate of the actual atomizer feed slurry. Enthalpy balances have been used to confirm agreement between slurry feed rate and flue gas flow measurements.

In addition to quantifying SO_2 removal and lime consumption performance for the spray-dryer/baghouse system, determination of particulate removal performance for the system was also an objective. This performance was determined by manual sampling of flue gas streams for particulate concentrations, using EPA methods. Particulate loadings were measured at the spray dryer inlet, spray dryer outlet, and fabric filter outlet.

Test Plan

The test schedule is summarized in Table 1. These tests were conducted between July 11 and October 8, 1983. The schedule shows three sets of conditions with low sulfur, Sarpy Creek coal/coke blend, and two sets with high sulfur Peabody Illinois coal. The Sarpy Creek coal/coke blend has a nominal sulfur content of 1.1 to 1.2 percent and a heating value of 9000 Btu/lb. New Source Performance Standards for utility boilers would require 75 to 80 percent SO_2 removal for boilers firing a fuel with this sulfur and heating value. In some localities, state or local regulations might require as high as 90 percent SO_2 removal with this fuel. Consequently, low sulfur tests were conducted at both 75 and 90 percent target SO_2 removal levels. Additionally, some tests were conducted at a fabric filter air-to-cloth ratio higher than the nominal value of 2:1.

Table 1. *Test Schedule and Desired System Operation Conditions[a]*

Fuel	*SO_2 Removal Level, %*	*Fabric Filter A/C Ratio, cfm/ft²*
Sarpy Creek Coal/Coke	*75*	*2:1*
Sarpy Creek Coal/Coke	*75*	*2.3:1*
Sarpy Creek Coal/Coke	*90*	*2:1*
Illinois Coal	*90*	*2:1*
Illinois Coal[b]	*90*	*2:1*

[a]All tests planned to be conducted at at 18°F approach to adiabatic saturation, 35 weight percent solids in the atomizer feed slurry, a 70 MW daytime boiler load, a once-per-hour baghouse cleaning frequency, and an attrition-type slaker.
[b]Calcium chloride addition tests.

Two sets of conditions were tested with the high sulfur coal. The coal was an Illinois No. 6 coal with a nominal 3.4 percent sulfur content and 10,700 Btu/lb heating value. Current New Source Performance Standards for utility boilers require approximately 90 percent SO_2 removal when coal of this sulfur content and heating value is burned. Consequently, only a 90 percent target SO_2 removal was tested with this high sulfur coal. The tests included baseline conditions of 90 percent removal with attrition-slaked lime and a second test run employing calcium chloride addition for lime utilization enhancement. Chloride addition to enhance lime utilization in spray-dryer/baghouse FGD systems has been tested previously in bench- and pilot-scale systems, but this is the first test of chloride addition at a full-scale utility installation. The enhancement effect is thought to occur because of the deliquescent properties of calcium chloride.

System Limitations

Several system limitations combined to restrict the amount and the type of data that could be collected. First, as mentioned earlier, Riverside Units 6 and 7 are peaking units. As such, they are rarely operated in the winter and only operate part-time during July to October. This part-time operation involves unit loads of 70 to 90 MW during weekday daylight hours, minimum load (30 to 50 MW) overnight during the week, and banking the boilers over the weekend. Although the FGD system was operated at desired SO_2 removal levels 24 hours per day, only about 12 hours per weekday of near full-load operation were available for evaluating FGD system performance. At the beginning of each 12-hour full-load period, the FGD system generally goes through a transient period due to a large increase in boiler load. On Mondays, the unit must undergo a cold start-up. Although this cycling provides a severe test of the capabilities of the system, it reduces the period of steady state operation at the desired SO_2 removal level over which lime reagent consumption can be measured.

Additionally, the Riverside system was the first utility-scale system designed and built by Joy/Niro as a demonstration unit. As the first unit built, the Riverside system has provided the opportunity to refine and modify design features for subsequent systems. Thus, some specifics of the Riverside system are different from what will be found in later designs. An example of this is the slurry feed system, which has been modified for subsequent systems to provide quicker response to transients such as load changes. At Riverside, the slurry feed system has a residence time of about 1.5 hours. This means that following an abrupt process change, such as a load change, it may take 3 to 4 hours for the slurry feed system to stabilize near steady-state conditions.

The impacts of the slurry feed preparation system residence time are particularly important at the Riverside station, as the normal station operation causes significant load changes at least twice per day. In fact, on some days during this test program, the unit load varied between 70 MW and 90 MW throughout the day. On these days, the unit never operated at one load long enough for the feed system to stabilize. On most other days, even if the load was steady all day, only 8 or 9 hours of the 12 hours of full load operation actually represented steady-state conditions.

Other aspects of the Riverside system's status as a demonstration unit affected the results of this program. For example, the system contains only one spray dryer module, while most utility systems will have multiple modules. In a multiple-module system, equipment problems which affect one individual module have a smaller impact on overall system performance. Being a one-module system, equipment problems tended to cause the entire system to have to be shut down, or operated at conditions other than those desired. Also, because the Riverside system is a demonstration, rather than a commercial system, some individual components of the system have not been installed with the redundancy that the vendor would likely install in a commercial system. These considerations have had a detrimental effect on both the amount of system downtime and the number of process-equipment-related upsets during the test program.

A final consideration which has affectd the test program involves the recent history of the Riverside station. For nearly the first 2 years of operation, the FGD system was used as a full-scale demonstration and testing unit by the process vendors. During this time, Joy/Niro had responsibility for the operation of the system, even though NSP actually provided operating personnel. Within the year prior to the test program, NSP had assumed responsibility for the operation of the FGD system. Immediately prior to the test program, the Units 6 and 7 boilers and FGD system were off-line for much of the winter and spring, as NSP does not need power production from these units during this time. During this long period of downtime, normal personnel turnover (promotions, retirement, transfers, etc.) resulted in a number of new operators rotating into the FGD system operating staff. At the start of the test program, then, the FGD system was being operated for the first time in several months with a staff of operators having little previous experience with the FGD system. Early in the program, the operators tended to revert to conservative higher spray dryer outlet temperatures during any minor upset, such as soot blowing in the boilers. This would move the operation away from the desired conditions and would preclude acquiring desired steady state operating data. As the program continued, these excursions occurred much less frequently as the operators became more comfortable with operating at test conditions.

Considering the previous discussions, it was not realistic to report availability of the system, as the availability of the Riverside system would tell little about that of a commercial utility, multimodule, dry FGD system on a new baseloaded boiler. The combined effects of weekly cold start-ups, frequent load changes, little redundance, and a somewhat undertrained operating staff at Riverside do little to promote a fair assessment of the potential availability of a commercial system.

However, the general operation of the system was closely observed during the test program. Much of the downtime or off-condition operating time was due to problems specific to the Riverside system. Others appear to be more generic to dry FGD systems. These more generic problems are discussed in the report, as they are more likely to occur in other systems.

Results

The discussion of the program results is divided into two areas: Operational Results, which includes a qualitative discussion of the operation of the system during the test program; and System Performance, which includes preliminary SO_2 removal, lime consumption, particulate and sulfuric acid removal data, and solid waste characteristics.

Operational Results

In general, the equipment that comprises the basis of the dry FGD system, the spray dryer and baghouse, were relatively trouble-free throughout the program. At the conditions tested, the spray dryer did not show evidence of potential problems (e.g., wheel nozzle pluggage, excessive buildup of solids on the walls, or formation of wet solids within the dryer). Some atomizer problems were observed, but most of these appeared to be caused by circumstances specifc to the situation at Riverside rather than being generic to the Joy/Niro system. These problems will be discussed further later in this section.

The baghouse also operated well, with no significant bag/fabric related problems being observed. In this short-term test though, long-term effects such as bag life or compartment wall corrosion rates could not be evaluated.

Some problems were observed in four specific areas—the slurry feed system, the ash handling system, the ball mill slaker, and in atomizer protection. The system vendors may have addressed these problems in system designs subsequent to Riverside, but the problems could be encountered in virtually any spray-dryer-based dry FGD system. Each of these areas is discussed below.

Slurry Feed System

In a recycle lime system, lime slurries containing up to 25 percent solids and recycle/lime slurries of 30 to 40 percent solids are commonly encountered. When dealing with slurries with a high solids content and high viscosity, problems (e.g., plugging of pump suction lines, solids buildup on tank walls, plugging of in-line screens used to remove oversize material, and loss of flow when switching pumps) are commonly encountered. Such problems were encountered often at the Riverside system. Years of operation of wet lime/limestone FGD systems have established means of dealing with such problems. The quantities of these slurries that must be dealt with in a spray dryer system, though, are much smaller than what would be encountered in a wet system. At Riverside, typical atomizer feed slurry rates are 150 to 200 gpm. In a similarly sized limestone wet FGD system, the slurry recirculation rate could be as high as 40,000 gpm. While some of the slurry handling problems of a wet FGD system may still be encountered in a spray dryer system, they will occur on a greatly reduced size of equipment. This should make both problem solving and routine maintenance easier. Another important point to be noted is that chemical scaling tendencies were not observed at Riverside.

Ash Handling System

In comparing the wet versus dry FGD systems, the spray dryer system has a slurry feed system that deals with much lower flow rates for a given unit capacity, but the quantities of dry ash and FGD by-products that must be moved around the system are substantially greater than for a comparably sized particulate collection device/wet scrubber system.

The problem with solids handling which most frequently occurred at Riverside involved the baghouse mechanical conveyors, blow pots, and the recycle bin rotary valve. Failures in any of these components could interrupt the flow of recycle material to the slurry mix tank, and cause the system to approach once-through operation.

Ball Mill Slaker

During this program, the ball mill slaker did not operate successfully for any extended period: the feed end of the slaker tended to plug with wet lime solids. While there are several possible reasons why the plugging continually occured, the actual cause was not identified.

The ball mill slaker problems at Riverside appear to be somewhat site-specific (ball mill slakers have operated successfully elsewhere). In retrospect, the slaker might have run more successfully at a higher water-to-lime ratio, resulting in a less viscous product slurry and less vapor release. However, in the attempts to run the ball mill slaker during the high sulfur tests in particular, the slaking water piping size did not allow operation at higher water-to-lime ratio at the lime slaking rates required. During the high sulfur tests, lime slaking rates averaged approximately four times that required for the normal low sulfur fuel at similar unit load and percent SO_2 removal conditions.

Atomizer Problems

Although the atomizer motor, gearbox, and nozzle wheel were generally trouble-free, on several occasions problems which could result in atomizer damage were observed.

Two scenarios for potential damage were observed. One occurred when the unit was forced to run from the basic, or less sophisticated, control station of the computer control system while the more sophisticated supervisory station was undergoing repair. The control software at Riverside does not have full interlock protection for the atomizer when running from the basic station. (Interlocks are software which automatically shut down the atomizer when given inputs that are indicators of problems which might result in damage to the atomizer.) While running in this mode, a minor problem involving loose wires to the atomizer oil circulating pump occurred, intermittently shutting off the pump. However, the basic station only gave the control operator an alarm rather than shutting down the atomizer automatically. The atomizer continued to run for several minutes without oil circulation and sustained gearbox damage.

The second scenario which could result in atomizer damage was observed on more than one occasion: it involved feeding slurry to the atomizer wheel when it was not rotating. Since the non-rotating wheel has a much lower hydraulic capacity than a rotating wheel, slurry fed to the standing wheel tends to overflow the wheel and can flow up the spindle to which the wheel is attached and enter the atomizer oil system. In such instances, the oil sump can be immediately emptied and flushed to avoid damage, but if the atomizer is operated before cleaning, the slurry in the oil can eventually cause gearbox damage.

Table 2. *SO_2 Removal Results, Low Sulfur Coal*

Average SO_2 Removal, %	*Spray Dryer Removal, %*	*Fabric Filter Removal, %*	*Reagent Ratio*	*Recycle Ratio*
74	*–[a]*	*–[a]*	*0.7*	*13:1*
75[b]	*67*	*8*	*0.6*	*14:1*
89	*78*	*11*	*0.8*	*11:1*

[a]Not measured.
[b]Increased air-to-cloth ratio at fabric filter; other tests at normal air-to-cloth ratio.

Table 3. *SO_2 Removal Results, High Sulfur Coal*

Average SO_2 Removal, %	*Spray Dryer Removal, %*	*Fabric Filter Removal, %*	*Reagent Ratio*	*Recycle Ratio*
88	*72*	*16*	*1.3*	*2:1*
89[a]	*62*	*27*	*1.0*	*3:1*

[a]High chloride concentration tests.

System Performance

The results of SO_2 removal and lime consumption measurements during this test program are summarized in Tables 2 and 3. Table 2 summarizes the low sulfur coal SO_2 removal results; and Table 3 summarizes those for the high sulfur coal tests.

For several reasons, the SO_2 removal results from the program cannot be expressed as 30-day rolling averages. First, the unit was never operated at one set of conditions for that long a period during the test program. Also, due to the operating characteristics of the peaking boilers, only 8 to 9 hours per day typically represent full load, steady state operation. Thus, the SO_2 removal and lime consumption results represent averages of values measured during steady state unit operation for a portion of a number of successive test days.

Lime consumption in Tables 2 and 3 is expressed as a reagent ratio, defined as:

$$\text{Reagent Ratio} = \frac{\text{Calcium in Fresh Lime Fed to System, lb-mole}}{SO_2 \text{ in Inlet Flue Gas, lb-mole}} \quad (1)$$

(This definition corresponds to that of the term "stoichiometric ratio" in many other dry FGD papers.)

Where possible, each value in Table 2 and 3 is supported by alternate calculations. For example, lime slurry feed rates are compared to lime weight belt readings, essentially a calcium balance on the lime slaker. Also, weigh belt readings have been compared against lime truckload delivery inventories. Flue gas flow rates are checked against slurry feed rates by enthalpy balance calculations.

Table 2 shows that SO_2 removal levels of nearly 75 percent and 90 percent were achieved for the low sulfur fuel with substoichiometric amounts of lime. This may be attributable to two factors. First, at 35 percent feed slurry solids in low sulfur operation, very high recycle rates are possible. This is seen in the recycle ratio values in Table 2, defined in this report as:

Recycle Ratio =

$$\frac{\text{Recycle Material in Atomizer Feed Slurry, lb/hr}}{\text{Fresh Hydrated Lime } [Ca(OH)_2]\text{, lb/hr}} \quad (2)$$

Since a large fraction of the baghouse catch and all of the spray dryer bottom solids are recycled, pilot plant results indicate that high sorbent utilization would be promoted. Additionally, analyses of the Sarpy Creek coal ash indicate a nominal 30 percent alkaline earth content (CaO, MgO, Na_2O, and K_2O), believed to have contributed to SO_2 removal. However, the "available alkalinity" in the coal ash was not directly measured.

The results in Table 2 also show the range of SO_2 removal in the spray dryer (S.D.) and fabric filter (F.F.). SO_2 removal in the fabric filter is calculated relative to the spray dryer inlet SO_2 concentration as:

SO_2 Removal$_{F.F.}$ =

$$\frac{[SO^2 \text{ into F.F.} - SO^2 \text{ out of F.F.}]}{[SO_2 \text{ into S.D.}]} \quad (3)$$

With this definition, spray dryer removal and fabric filter removal can be summed directly to yield overall removal values. The results show that, at 75 percent overall SO_2 removal, fabric filter removal contributes little to the overall removal. This occurs because sorbent utilization is very high in the spray dryer itself. For 90 percent removal, the fabric filter contribution increases somewhat, but in an amount roughly proportional to the increase in overall removal level.

Table 3 summarizes the high sulfur coal test results. For the first set of data, corresponding to normal low chloride operation, greater than stoichiometric amounts of fresh lime were required. Several factors probably contributed to this effect. One may be that, because of the increased lime addition rates, the recycle ratio was greatly reduced relative to low sulfur values in order to maintain the total solids in the slurry at the desired weight percent value. Also, the Illinois coal ash (being nonalkaline) contributed no alkalinity to the SO_2 removal reactions. For the first set of high sulfur data, the fabric filter contribution to overall SO_2 removal appears to be more important than for low sulfur operation.

Chloride addition has been reported by others to promote increased sorbent utilization in spray-dryer-based FGD systems. The benefits are thought to result from the deliquescent properties of calcium chloride, which delay complete drying of the droplets in the spray dryer and result in higher residual moisture levels in the fabric filter solids. The second set of SO_2 removal data in Table 3 corresponds to the addition of calcium chloride at levels which result in a chloride content of 1 percent in the fabric filter solids collected. This chloride level in the fabric filter solids was recommended by the system vendor, Niro Atomizer, as being an optimum value for lime utilization enhancement, based on pilot-scale studies conducted at their Copenhagen, Denmark, test facility. At Riverside, this solids chloride level required a liquid-phase chloride concentration of about 7,000 ppm in the atomizer feed slurry. For the recycle rates at Riverside, fresh makeup of calcium chloride accounted for about half of this liquid-phase content, and the remainder dissolved from the recycle material. The results in Table 3 show that chloride addition significantly reduced the lime reagent ratio requirements to achieve nearly 90 percent removal; the lime requirement was reduced by about 25 percent.

The SO_2 removal results for these high chloride tests indicate increased SO_2 removal across the fabric filter relative to that for the baseline high sulfur coal test. This indicates that the benefits of high chloride level on residual moisture level in the fabric filter have a greater impact on SO_2 removal than impacts within the spray dryer.

At Riverside, with chloride levels in the fabric filter solids at 1 percent, residual moisture levels increased from below 1 percent to nearly 2 percent. These moisture levels are still low enough to avoid problems which result from handling wet solids. Also, no buildup of wet solids on the spray dryer walls occurred during testing, and solids collected at the bottom of the spray dryer contained moisture levels below 3 percent. These tests were conducted at an 18°F approach to adiabatic saturation at the dryer outlet, just as were all previous tests.

Material balance calculations indicate that, for a coal such as the Illinois coal fired in the high sulfur tests at Riverside, a chloride content of around 0.3 percent would provide the chloride levels of this test. This would be an uncharacteristically high chloride level for a typical 3.4 percent sulfur coal. However, based on published bulk prices for calcium chloride, it appears that it would be economic in this case, disregarding capital cost considerations, to operate at high chloride levels even if virtually all of the chloride must be added as calcium chloride. For a 3.4 percent sulfur coal with a higher chloride content (0.1 percent or better), the economics would likely be improved. Additionally, a makeup water source with a significant chloride content, such as some cooling tower blowdowns, should further improve these economics.

High chloride levels could potentially have a negative impact on system corrosion rates. Corrosion rate impacts could not be measured in this short-term test. No profound impacts were observed, however.

Mass Loading Measurement Results

Table 4 presents mass loading results for both the high sulfur and low sulfur coal test periods. The results show that the spray dryer increases the grain loading at the fabric filter inlet to 3 to 5 times that of the spray dryer inlet value. The data also show that particulate removal levels remained high throughout the test program. Removal efficiencies across the fabric filter varied from 99.95 to over 99.9 percent. The emission levels in Table 4 are expressed as grains per dry standard cubic foot. In all cases, particulate emission rates measured were below the current NSPS level for utility boilers (0.03 lb/10^6 Btu).

Flue Gas SO_3 Measurement Results

Flue gas SO_3 concentration was also measured. For the low sulfur coal tests, no measurable SO_3 levels were detected at either the spray dryer inlet or fabric filter outlet. The inability to meausre SO_3 at the dryer inlet is apparently related to the alkaline nature of the Sarpy Creek coal ash.

Measurable levels of SO_3 were found during the high sulfur test periods.

Table 4. *Flue Gas Mass Loading Summary*

Sampling Location	*Mass Loading, gr/dscf*	
	Low Sulfur Tests	*High Sulfur Tests*
Spray Dryer Inlet	*3.2 to 4.1*	*2.8 to 4.1*
Spray Dryer Outlet	*11.0 to 13.8*	*14.9 to 17.2*
Fabric Filter Outlet	*0.001 to 0.003[a]*	*0.001 to 0.008[b]*

[a]Equivalent to 0.002 to 0.007 lb/10⁶ Btu.
[b]Equivalent to 0.002 to 0.018 lb/10⁶ Btu.

Spray dryer inlet values were measured at 2 to 6 ppm SO_3. Fabric filter outlet values varied from 0.1 to 0.5 ppm. Based on data from a limited number of days where the spray dryer inlet and fabric filter outlet SO_3 concentrations were measured simultaneously, removal efficiencies of 90 percent or better across the system were indicated.

Solid Waste Characteristics

Solid waste characteristics for samples collected during both low sulfur and high sulfur test conditions were evaluated in a laboratory-scale test program. Characteristics of both untreated and cured solid wastes were measured. The cured solid wastes showed best properties for permeability coefficients and unconfined compressive strength when 30 to nearly 50 percent moisture was added to the dry solids before curing. For the 75 percent removal low sulfur coal tests and the high sulfur coal baseline 90 percent removal tests, permeability coefficients for cured samples were in the range of 10^{-5} to 10^{-7} cm/sec, typical of treated FGD sludge. Unconfined compressive strengths for these samples were over 100 psi. For the high sulfur coal chloride addition test, however, the permeability coefficient of the cured wastes was increased to the 10^{-4} range, and the unconfined compressive strength was reduced to 55 psi. Both changes indicate poorer solid waste characteristics, apparently resulting from high chloride levels.

Summary and Conclusions

Based on results from the 3-month test program on the NSP Riverside dry FGD system, the following conclusions are presented:

- In general, the Riverside system ran quite well. None of the problems anticipated for spray dryer systems (e.g., rotary atomizer wheel pluggage, buildup of wet solids on dryer vessel walls, or wetting of fabric filter bag surfaces during upset conditions) were observed.
- Some problem areas at Riverside appear to be potential sources of problems on similar dry FGD systems. These include typical problems with mixing and pumping slurries with a high solids content, solids handling equipment which requires continual maintenance, and sometimes inadequate atomizer protection during upset conditions.
- At sulfur levels up to a nominal 3.4 percent, high SO_2 removal efficiencies (nearly 90 percent) were readily achievable in the relatively short-term periods of this program. For the low sulfur Sarpy Creek coal/coke mixutre, substoichiometric amounts of lime were required even at 90 percent SO_2 removal. This was attributed to the alkaline nature of the Sarpy Creek coal ash. For the high sulfur Illinois coal, 90 percent SO_2 removal required reagent ratios of about 1.3 to 1.4 moles limes per mole of inlet SO_2.
- Calcium chloride addition to the atomizer feed slurry to achieve chloride levels of about 1 percent in the fabric filter solids catch appeared to be successful in promoting lime utilization. For the high sulfur tests, the lime reagent ratio to achieve 90 percent SO_2 removal was reduced from 1.3 to 1.4 down to a range of 0.9 to 1.1 moles lime per mole of inlet SO_2. This chloride level would correspond to 0.3 percent chloride in a nominal 3.4 percent sulfur coal. Even for a low chloride, high sulfur coal, high chloride levels achieved through calcium chloride addition appear to be cost effective for reducing lime consumption.
- Particulate control efficiencies were high throughout the test program, maintaining outlet grain loadings well below required levels. In spite of baghouse operation within 18°F of the adiabatic saturation temperature and very high baghouse inlet grain loadings, no bag-fabric-related problems were observed and flange-to-flange pressure drop remained acceptably low.
- For the high sulfur test periods, a limited number of data indicated SO_3 removal levels of 90 percent or greater.
- Solid waste characteristics for both the low sulfur 75 percent SO_2 removal test and the high sulfur baseline 90 percent SO_2 removal test appear to be acceptable for landfilling. A deterioration of solid waste characteristics was noted, however, for the high sulfur chloride addition tests.

Metric Equivalents

Nonmetric units are used, for the most part, in this Summary because of their customary usage in the electric power industry. Readers more familiar with their metric counterparts may use the following equivalents:

Nonmetric	Multiplied by	Yields Metric
Btu	1.06	kJ
°F	5/9(°F-32)	°C
ft	30.48	cm
ft^2	0.093	m^2
ft^3	28.3	L
gal.	3.79	L
gr	0.065	g
hp	746	W
in^2	6.45	cm^2
lb	0.45	kg

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The complete report, entitled "Field Evaluation of a Utility Dry Scrubbing System," (Order No. PB 85-207 488/AS; Cost: $26.50, subject to change) will be available only from:
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