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Project Summary

Studies of Flue Gas Desulfurization at Louisville Gas and Electric's Paddy's Run Station

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Between the Spring of 1973 and the Fall of 1976, Louisville Gas and Electric's Paddy's Run lime flue gas desulfurization (FGD) system logged more than 4000 hours of operation without any major process or mechanical problems. Due to this operating success when other similar systems were encountering numerous problems, EPA funded a 6-month evaluation study at Paddy's Run. A program was implemented to characterize the system in its normal mode of operation and to conduct tests which would simulate conditions typical of other lime-based systems.

The Paddy's Run FGD system normally uses carbide lime, a by-product in the production of acetylene, as the alkaline additive. Contaminants in the carbide lime, notably thiosulfate, are responsible for minimizing the sulfite oxidation rate which helps to maintain scale-free operation of the system. Substitution of commercial lime for carbide lime resulted in gypsum scaling in the scrubber. Magnesium addition (~3000 ppm) with commercial lime reestablished scale-free operation and improved SO_2 removal dramatically. Addition of either carbide lime or commercial lime with magnesium resulted in sulfite oxidation levels well below those required to operate subsaturated with respect to gypsum (less than about 16 percent). Under these conditions, all of the sulfate formed precipitated in a solid solution with calcium sulfite hemihydrate.

Additional tests examined the effect of chloride addition, lime addition, point location, and the reaction tank volume.

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

Introduction

Louisville Gas and Electric (LG&E) Company's Paddy's Run No. 6 flue gas desulfurization (FGD) system was one of the first commercial-scale FGD units to be operated successfully in the U.S. Between its start-up in the Spring of 1973 and the Fall of 1976, the unit logged close to 4000 hours of operation without any major process or mechanical problems. Because of the demonstrated success of the Paddy's Run system, the EPA sponsored a test program to determine the factors which account for the successful operation of this FGD system.

At the time that this test program was conceived, a wide range of operating problems were being encountered in many FGD units which were operating. One of the more serious process

problems was chemical scaling in the scrubber. A method being investigated by many experimenters to avoid this problem was to operate the FGD system in such a manner that the slurry liquor remains subsaturated with respect to calcium sulfate dihydrate (gypsum). Recognizing this fact, the EPA conceived a program whose overall objectives were to characterize the performance of the LG&E system in its "normal" operating mode, and to determine the features which make it possible for this system to operate in a subsaturated gypsum mode. Additional tests were planned to simulate conditions more typical of those encountered in other lime-based systems and to determine the effects of changes in important process operating parameters.

The intent of the program was to provide useful information which could be applied to other FGD systems. Ultimately, it was hoped that data from the successful operation at Paddy's Run could be extrapolated to other lime/limestone systems.

System Description

The flue gas from the Paddy's Run No. 6 boiler (65 MW) first passes through an ESP and then is treated in one of two parallel marble-bed scrubber modules. The inlet flue gas typically contains 1500-3000 ppm of SO_2. During the EPA test program, the boiler was operated at half load, requiring the use of only one scrubber module.

The major features of the FGD unit are shown in Figure 1. Each scrubber module contains two marble beds in series, followed by two banks of chevron mist eliminators. The scrubbing liquor is introduced to the scrubber through spray nozzles below each bed. The scrubber effluent liquid streams consist of the overflow liquors from the two marble beds as well as the scrubber bottoms liquor. Approximately 7 cm (3 in.) of marbles are contained on each bed. The downcomer weirs are of such a height that the active gas/liquid contact zone on each bed is about 25 cm (10 in.).

A unique feature of this system is the mixing well into which the three scrubber effluent streams, the clarifier overflow liquor, and the lime additive slurry flow before they enter the main reaction tank. The effective residence time of the mixing well is about 30 seconds, whereas the residence times of the main hold tank and surge tank are about 35 and 5 minutes, respectively (all of these residence times are for half-load conditions). The residence time of the liquor on the beds averages 30 seconds, while the normal scrubber L/G is about 7.5 l/Nm³ (56 gal./10³ scf).

The alkaline additive normally used at Paddy's Run is carbide lime, purchased from a local acetylene manufacturer. The two basic steps in producing acetylene are: (1) commercial lime and coke are heated to form calcium carbide, and (2) the calcium carbide is then reacted with water to form acetylene and calcium hydroxide, commonly called carbide lime. This regenerated carbide lime retains some impurities from the processing which are carried into the lime FGD system at Paddy's Run. The carbide lime additive is stored as a 25 percent slurry in an additive tank and is fed to the draft tube on pH demand. The pH of the reaction tank effluent is generally 8.

The surge tank effluent is the scrubber feed stream. In addition, a portion of this stream is routed to the clarifier to maintain a circulating slurry solids level of 10 weight percent. The clarifier underflow (about 20 percent solids) is sent to a set of two vacuum filters which produce a filter cake containing 35-40 weight solids.

System makeup water comes from: (1) mist eliminator wash water, (2) additive slurry, (3) turning vane spray wash water, and (4) seal water for pumps and mixers. Mist eliminator and turning vane spray washes are intermittent; seal water and the lime slurry are continuous makeup water sources.

Program Objectives

The overall objective of the test program was to determine quantitatively the reasons for the operating success of the Paddy's Run System. This unit had not experienced problems such as chemical scaling or mist eliminator pluggage which have been associated with many other lime and limestone SO_2 scrubbing systems. One important aspect of this trouble-free operation is the system's ability to operate subsaturated with respect to gypsum. This permits the system to operate without gypsum scaling problems.

It has been established that subsaturated conditions are related to sulfate coprecipitation with calcium sulfite. Laboratory studies have verified the formation of calcium sulfite-sulfate hemihydrate solid solution[1]. These studies indicate that sulfate can be incorporated into the calcium sulfite lattice to a maximum sulfate to total sulfur ratio of about 0.16. In addition, the sulfate/total sulfur ratio in the solids is directly related to the gypsum relative saturation in the liquor. As long as the sulfate production rate does not exceed the rate at which sulfate can be incorporated into the sulfite lattice, the liquor from which the solids precipitate will remain subsaturated with respect to gypsum. Gypsum scaling is not a problem in a liquor which is subsaturated with respect to gypsum.

There were several areas of interest regarding operation in the subsaturated mode. The primary area is the sulfite oxidation rate. System parameters which may impact the oxidation rate or otherwise influence the subsaturated mode of operation include additive type
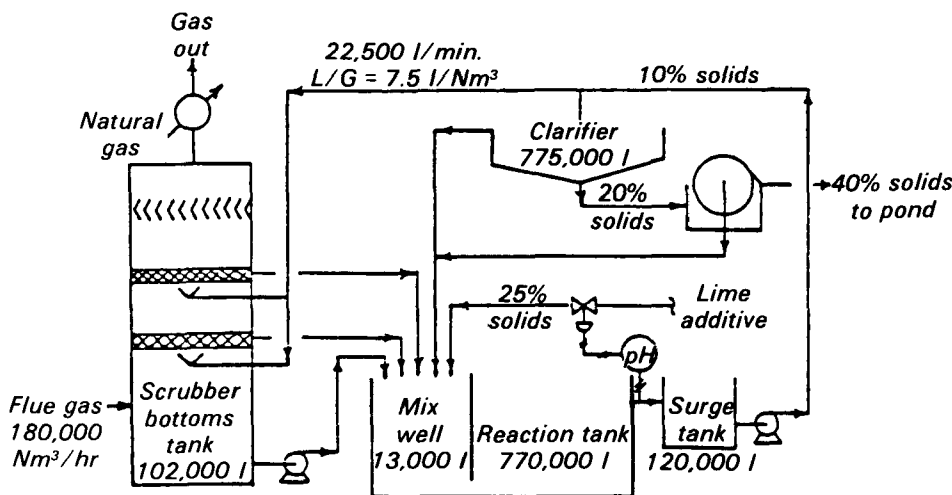

Figure 1.   Simplified flow diagram - Paddy's Run No. 6 FGD system.

(carbide lime vs. other additives), reaction tank configuration, and soluble ion concentrations. It was anticipated that studies involving these parameters would yield insight into the question of why subsaturated gypsum operation is possible at Paddy's Run.

To fulfill the overall program objectives, four test phases were originally outlined:

Phase I—Carbide Lime Testing.
Phase II—Commercial Lime Testing.
Phase III—Hold Tank Modification Testing.
Phase IV—Chloride/MgO Testing.

The objectives of each test phase are discussed below.

Phase I—Carbide Lime Testing

The initial phase of testing involved characterizing the LG & E Paddy's Run No. 6 FGD system in normal operation; i.e., using carbide sludge as the lime additive. The results of this test phase served as the "base case" for comparison with subsequent test results.

Phase II—Commercial Lime Testing

The second phase of testing was performed using commercial lime as the alkaline additive rather than carbide lime. The major goal of this phase was to identify differences in operation which might be caused by the change in the lime additive. Particular attention was given to monitoring oxidation rate effects because oxidation was known to be a key variable in operating subsaturated with respect to gypsum.

All subsequent tests were conducted using commercial lime as the additive.

Phase III—Hold Tank Modification Testing

Lime systems have the advantage of a very rapid additive dissolution rate. Taking only this factor into account, high lime utilization efficiencies should be attainable even for very short reaction tank residence times. In one portion of this test phase, the reaction tank residence time was reduced to study the impact of this change on the performance of the system.

A mechanical feature of LG&E's Paddy's Run FGD unit, which is unique to that particular system, is the mixing well. It has been suggested that a key to the success of the LG&E system is associated with the operation of this mixing well. This hypothesis was tested in a second reaction tank modification test which eliminated the effect of the mixing well. This was accomplished by changing the lime addition point from the mixing well to the reaction tank.

Phase IV—Chloride/MgO Testing

The final phase involved testing the effects of chloride and magnesium levels on subsaturated gypsum operation. It had been reported that increased chloride ion concentrations may decrease the amount of sulfate which can be purged from the system as a solid solution with calcium sulfite. Indications that increasing magnesium concentrations enhance the coprecipitation of calcium sulfate with calcium sulfite had also been reported. Supporting evidence for these claims was not found in recent laboratory studies by Jones[13]; however, measurements of these effects in an actual operating system were desired during this test phase.

All major tests outlined for each test phase were conducted during the test program. However, due to differences encountered between commercial and carbide lime operation, the order of the tests had to be changed. As discussed in the Results section, operation with commercial lime led to scaling in the scrubber. Therefore, magnesium addition was employed to eliminate the scaling conditions prior to the hold tank modifications test phase. Consequently, the test phases were renumbered to:

Phase I—Carbide Lime Testing.
Phase II—Commercial Lime Testing.
Phase III—MgO Addition Testing.
Phase IV—Hold Tank Modification Testing.
Phase V—Chloride Addition Testing.

Magnesium addition was necessary throughout the last three test phases to maintain system operability.

Results

Phase I—Carbide Lime Testing

Phase I was conducted over a 6-week period beginning mid-November 1981. The FGD system operated according to LG&E's standard operating procedures during this period. (The only change was that the relatively high magnesium-content liquor normally used to slurry the carbide lime was not used, so that carbide and commercial lime could be compared with low dissolved magnesium concentrations in the scrubbing liquor.) The scrubber feed pH set point was 8.0 which resulted in scrubber effluent liquor pHs of 4.5-5.0. The L/G during this operating period (and through most of the program) was about 7.5 l/Nm³ (56 gal./10³ scf).

The SO_2 removal efficiency ranged from 75 to 83 percent according to the DuPont on-line analyzer. The DuPont analyzer measured inlet SO_2 concentrations between 1800 and 2000 ppm. Wet test methods showed inlet SO_2 concentrations of 2000 to 2500 ppm. The SO_2 removal efficiency calculated from wet test results was about 5 percent lower than that measured from DuPont analyzer results because of higher manually determined outlet concentrations.

The concentrations of important dissolved ions which were measured in the system during Phase I are plotted in Figure 2. Note that the calcium level increased by about 50 to 70 percent across the scrubber due to the dissolution of solids in the low pH scrubber liquor. Also, note that the dissolved sulfate level also increased across the scrubber, but only by about 20 to 40 percent.

The calcium solids dissolution which occurred in the Paddy's Run system at base case conditions is a significant operating characteristic. Roughly 30 to 50 percent of the total alkalinity required for SO_2 removal was being derived from calcium sulfite dissolution in the scrubber. A significant portion of the sulfate ion increase was also due to solids dissolution since some sulfate exists in a solid solution with the calcium sulfite. The large amount of solid phase alkalinity required was due to the relatively low L/G employed which limited the total available liquid phase alkalinity. The relatively long slurry residence time on the marble beds (20-30 seconds) provided the time required for the relatively slow solid dissolution reactions to occur. Thus, the mechanical design of the Paddy's Run marble bed scrubbers resulted in large percentage increase in calcium ion concentration which was observed across the scrubber.

If the concentrations of both Ca^{++} and $SO_4^=$ increase across the scrubber, the gypsum relative saturation will also increase. This effect is shown in Figure 3. Since the system oxidation level remained below 15 percent during Phase I, the scrubber feed liquor remained subsaturated with respect to gypsum. The lower bed downcomer

liquor was also subsaturated during most of this test phase, except for a short period when the system oxidation level approached 15 percent and the inlet relative saturation approached 1.0.

However, the increased gypsum relative saturation across the scrubber, which was caused primarily by calcium solids dissolution, was not sufficient to create scaling problems during Phase I.
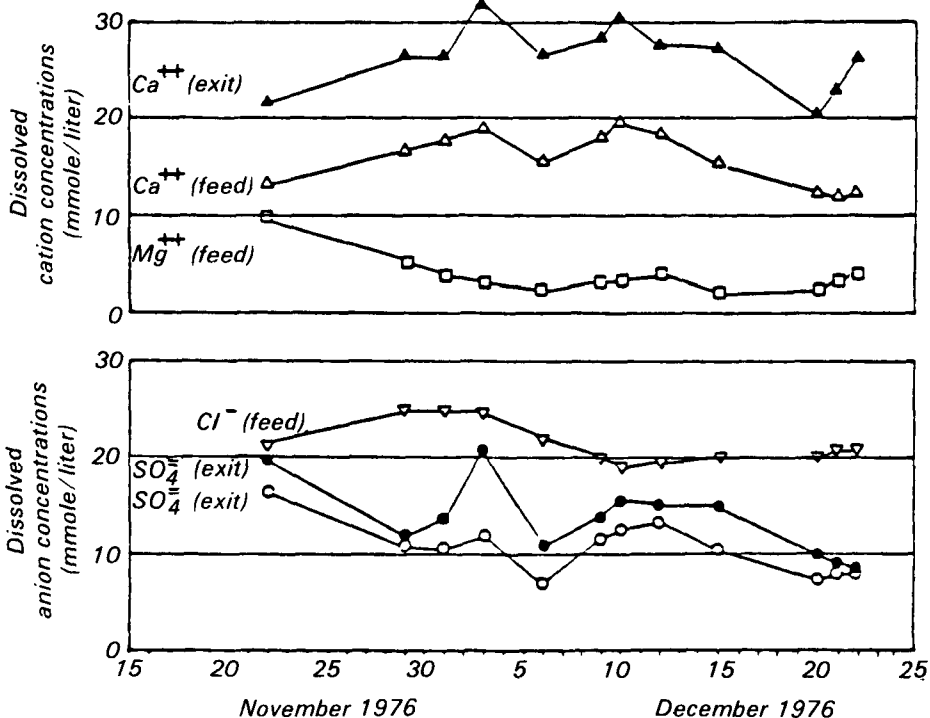
Phase II—Commercial Lime Testing

In some respects, operation with commercial lime was very similar to operation with carbide lime The SO_2 removal obtained with commercial lime at base case conditions was equivalent to that obtained in Phase I (75-80 percent). Dissolution of calcium solids in the scrubber was still necessary to provide the alkalinity needed for SO_2 removal. Figure 4 shows that the percentage increases in Ca^{++} (60-70 percent) and $SO_4^=$ (20-30 percent) were equivalent to the increases noted across the scrubber during Phase I.

The major difference between operation with commercial lime and carbide lime was that the oxidation rate was higher with comercial lime. The effect of this change in oxidation rate is shown in Figure 5.

In the case of carbide lime operation, the relative saturation of gypsum in the scrubber feed stream remained about 0.7 to 0.75 at an oxidation fraction of 0.1. Due primarily to the dissolution of calcium solids, the gypsum relative saturation of the lower bed exit stream increased about 30 percent to between 0.9 and 1.0.

Operation with commercial lime resulted in a sulfite oxidation fraction of 0.15. As a result, the scrubber feed gypsum relative saturation varied
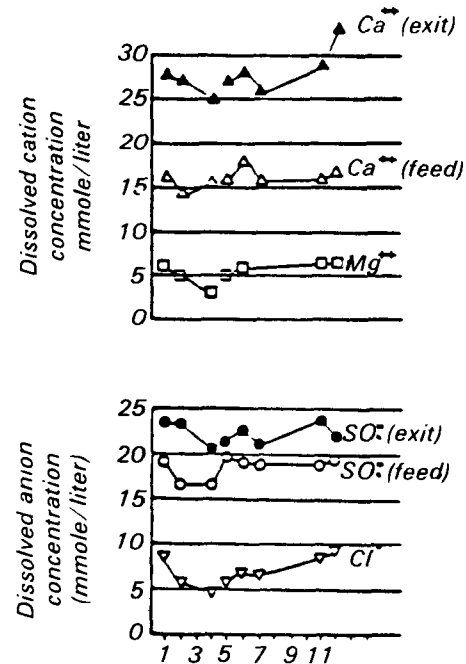

Figure 2. Liquid phase concentrations - Phase 1.
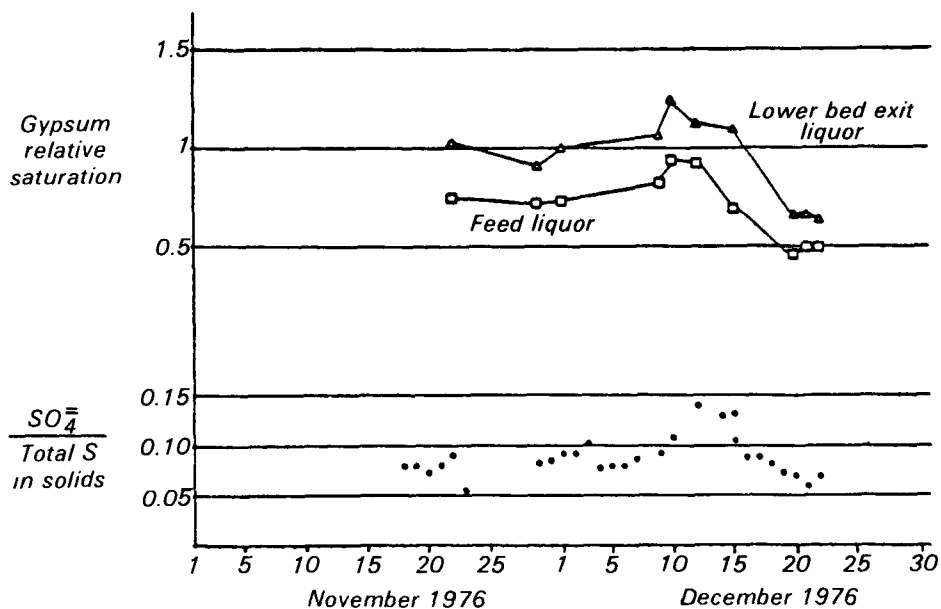
Figure 3. Relative saturation and percent oxidation - Phase I.

Figure 4. Liquid phase concentrations - Phase II

between 0.9 and 1.0. Since the increases in Ca^{++} and $SO_4^=$ across the lower bed were approximately equal during the two phases, the increase in gypsum relative saturation was about 30 percent in both Phase I and Phase II. The resulting lower bed effluent gypsum relative saturation was between 1.1 and 1.3 during Phase II.

Gypsum relative saturations less than 1.3 are below what is generally considered to be the critical scaling limit. However, the lower bed effluent stream is a composite of the liquor leaving the entire lower bed. Regions on the bed which were burdened with higher than average SO_2 loadings would have experienced higher than average gypsum relative saturations. In this situation, localized scaling might be expected. This is exactly what was observed throughout Phase II, even when the scrubber liquid rate was raised to its maximum value.

The results from Phases I and II support the data gathered during coprecipitation laboratory studies which were performed by Radian for EPA[2]. In both phases, the gypsum relative saturation of the scrubber feed liquor

approached equilibrium as the solid sulfate/total sulfur ratio approached 0.16. This is about the maximum amount of sulfate which can be incorporated into the calcium sulfite hemihydrate crystal lattice. Infrared scans run on solid samples from both phases indicate that all of the sulfate in the solid phase present was calcium sulfite-sulfate solid solution. If any of the gypsum solids formed in the scrubber during Phase II were carried to the reaction tank, they were redissolved because the reaction tank liquor was subsaturated with respect to gypsum.

Additionally, further work sponsored by the EPA has identified several reduced sulfur compounds as well as polynuclear aromatics in the carbide lime[2]. Thiosulfate is one of these compounds which is a known inhibitor of the oxidation reaction of sulfite to sulfate. It is very likely that the successful operation of the Paddy's Run system with carbide lime is a result of these contaminants minimizing the sulfite oxidation rate. When commercial lime was used without inhibitors, the sulfite oxidation increased to the point where the increase in gypsum relative saturation across the scrubber resulted in chemical scaling.

Phase III—MgO Addition Testing

Once it was recognized that scaling under base case conditions was unavoidable, a decision to begin magnesium addition was made. Addition of magnesium should increase liquid phase alkalinity and decrease the requirement for solids dissolution across the scrubber. It was hoped that lower solids dissolution rates would alleviate the scaling.

The most dramatic effect of magnesium addition was its impact on the liquid phase most alkalinity and the resulting SO_2 removal efficiency. Table 1 summarizes this effect. Magnesium concentrations of 170 mmole/liter (~4000 ppm) resulted in removal efficiencies above

99 percent. At magnesium concentrations of about 90-95 mmole/liter (~2000 ppm), removals between 90 and 95 percent were obtained which were still significantly higher than the 75 percent achieved with either commercial or carbide lime alone.

In addition to the increased SO_2 removal efficiency, the higher magnesium levels had a major impact on system operability. This is shown in Figure 6. When the magnesium concentration was maintained at 170 mmole/liter (4000 ppm), essentially no calcium dissolution occurred in the scrubber. Under these conditions, the sulfate/total sulfur ratio in the solid phase was about 0.05 and the gypsum relative saturation was below 0.2 throughout the scrubbing loop. However, when the magnesium concentration was dropped to 90 mmole/liter (~2000 ppm), the scrubber effluent pHs dropped, and calcium dissolution was noted in the scrubber. During the same period the solid phase sulfate/total sulfur ratio rose to 0.13, and gypsum scaling was observed on scrubber internals. The gypsum scale thus formed was dissolved as the magnesium level was again increased.

It was noted, however, that operation with magnesium addition is not without its drawbacks. High magnesium levels appear to lead to solids settling and dewatering problems. During Phase III, operation with magnesium concentrations above 180 mmole/liter (~4400 ppm) led to clarifier operating problems. The increased magnesium levels increased the soluble sulfite and sulfate levels and created conditions which were conducive to excessive nucleation. This created small solid crystals which would not settle very efficiently. Clarifier settling problems were observed for almost a week following 2 days of operation at 4400 ppm magnesium. A reduction in the magnesium level reestablished the formation of rosette crystal structures which settled much more efficiently. Figure 7 is an electron micrograph of scrubber solids when the dewatering system was performing satisfactorily.
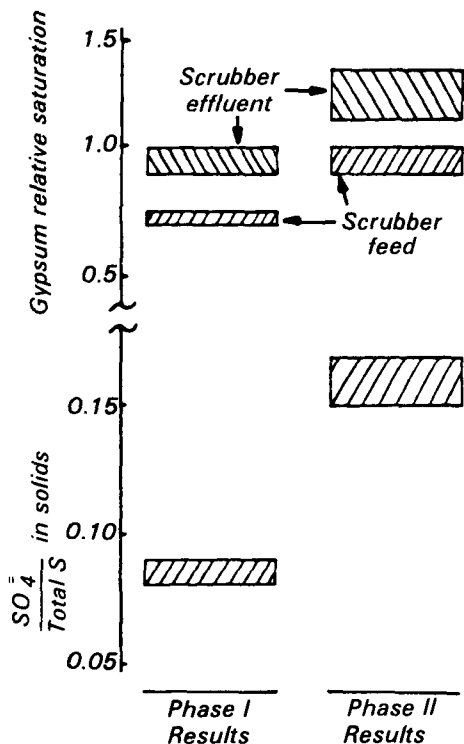

Figure 5. Comparison of oxidation rate and gypsum relative saturation values - Phase I vs. Phase II.

Table 1. Effect of Magnesium Concentration On SO_2 Removal Efficiency

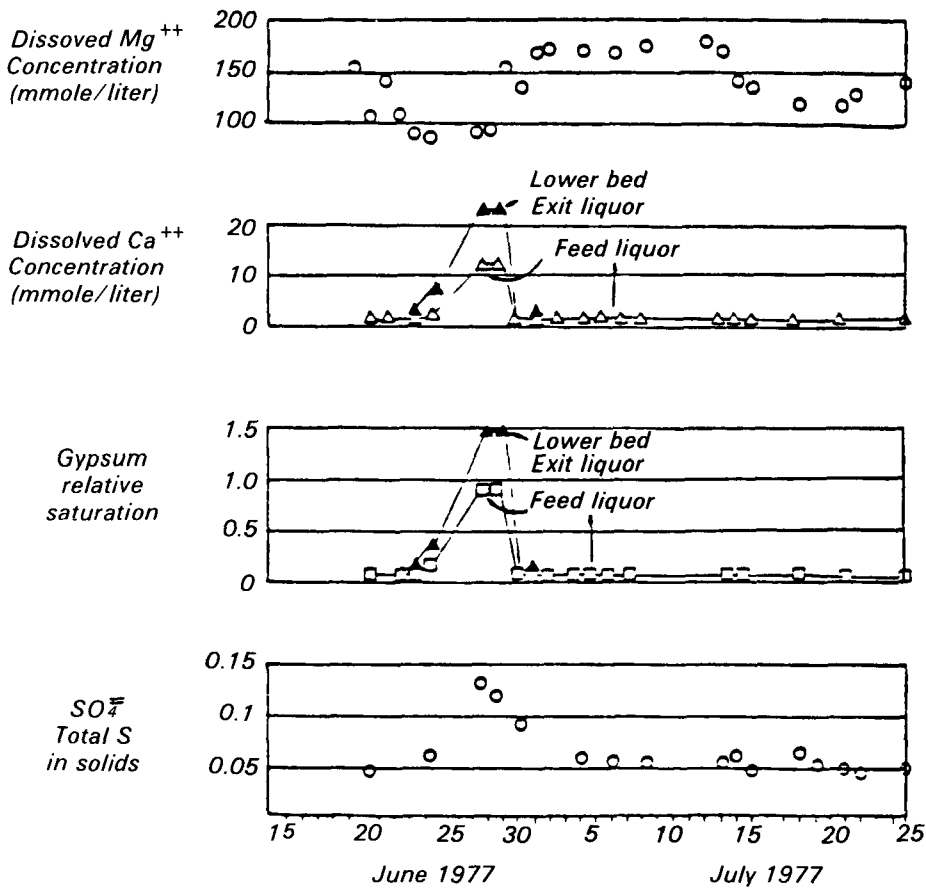|	Dissolved Magnesium Content (ppm)	SO_2 Removal Efficiency (%)
Note: Inlet flue gas contained ~2000 ppm SO_2 and the dissolved chloride concentration in the scrubber liquor was <500 ppm.	200 (baseline)	75
	2000	90-95
	4000	99[+]

Dissoved Mg^{++} Concentration (mmole/liter) 200 150 100

Lower bed
Exit liquor
Feed liquor

Dissolved Ca^{++} Concentration (mmole/liter) 20 10 0

Lower bed
Exit liquor
Feed liquor

Gypsum relative saturation 1.5 1.0 0.5 0

SO$_4^=$ Total S in solids 0.15 0.1 0.05

15 20 25 30 5 10 15 20 25

June 1977 | July 1977

Figure 6. Impact of magnesium level on oxidation and gypsum scaling potential (Phase III).

Phase IV—Hold Tank Modification Testing

Two reaction tank modifications were tested during Phase IV operation. First, the mixing well effect was eliminated by relocating the lime additive point from the mixing well to the main reaction tank. In a second test, the residence time of the reaction tank system was reduced from about 35 minutes to about 5 minutes by bypassing the main reaction tank. Both tests were conducted with Mg(OH)$_2$ addition.

Operation in both configurations proved to be successful. As expected, the effects of magnesium on SO$_2$ removal for each configuration were quite similar to those shown in Phase III However, there were some differences in the gypsum relative saturations and the sulfite oxidation fraction for the two configurations. These differences are shown in Figure 8. Oxidation was somewhat higher during operation in the reduced residence time configuration.

Mixing Well Elimination Test

Basically, the effects of magnesium on total system operation in this configuration were similar to those experienced in Phase III. With the lime additive point change, the system remained operable at magnesium levels above 100 mmole/liter (2400 ppm).
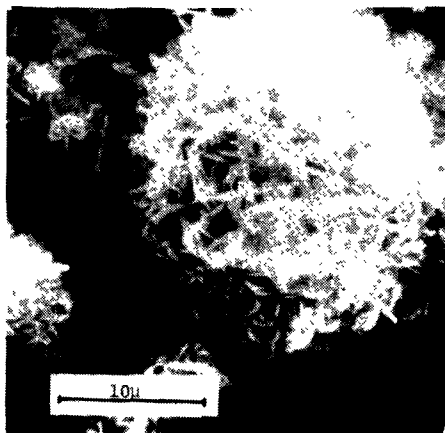
Figure 7. Typical rosette formed in lime system (July 5, 1977).

◄ Mixing well elimination test ➡ | Reduced reaction ◄Volume test➡

Dissolved Mg^{++} Concentration (mmole/liter) 200 100 0

Lower bed
Exit liquor
Feed liquor

Dissolved Ca^{++} Concentration (mmole/liter) 20 10 0

Lower bed
Exit liquor
Feed liquor

Gypsum relative saturation 1.5 1.0 0.5 0

SO$_4^=$ Total S in solids 0.15 0.10 0.05

25 1 5 10 15 20 24
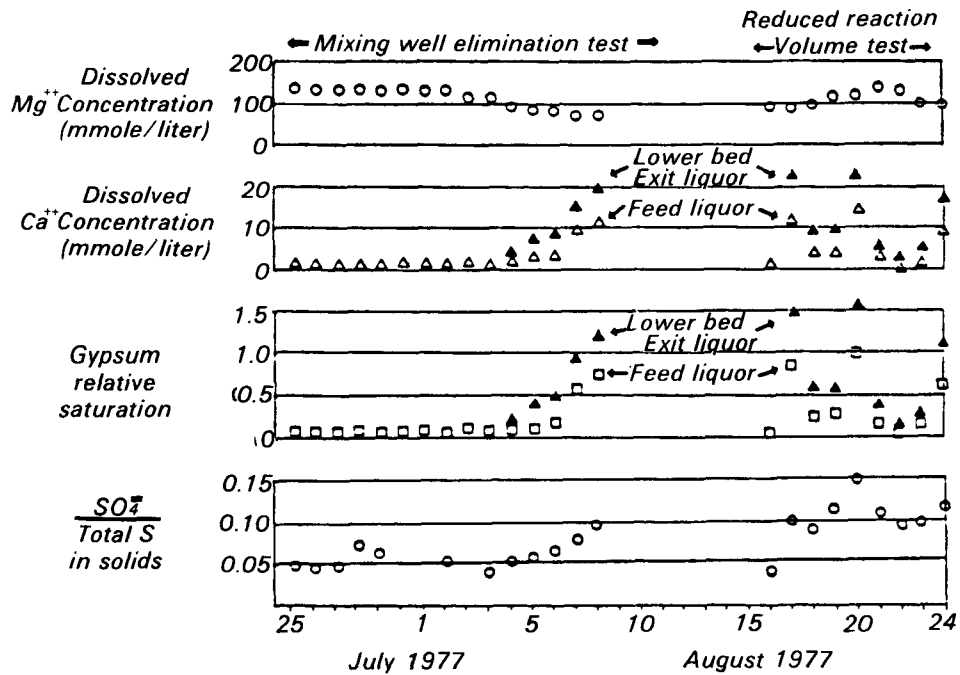
July 1977 | August 1977

Figure 8. Impact of magnesium on system operation during Phase IV.

Slurry streams subsaturated with respect to gypsum were present throughout the system, and the solid phase sulfate/total sulfur ratio remained about 0.05 to 0.07. When the magnesium level was reduced and maintained below 100 mmole/liter, however, significant calcium dissolution occurred in the scrubber, and the oxidation fraction and gypsum relative saturations approached inoperable levels.

The main effect expected from the lime additive point change was an alteration in the product crystal structure. When the lime additive enters the mixing well, lime particles dissolve directly into the scrubber effluent liquor, which is relatively high in soluble sulfite and has a relatively low pH. Locally high relative saturations thus occur in the region of the dissolving solid $Ca(OH)_2$ particles which promotes nucleation. In the configuration where lime enters the main reaction tank, the dissolving lime particles encounter reaction tank liquor which has a higher pH and lower soluble sulfite concentration. Since the localized relative saturations generated in this situation would not be expected to be as high, more orderly crystal growth should be promoted by the "no mixing well" configuration.

The results from the draft tube elimination test support this theory. Shortly after the lime additive point was moved from the mix well, the crystal morphology began changing from the rosettes which were produced during Phase III to structures which were more platelet-like. During this transition, solids settling problems were encountered. However, continued operation in the "no mixing well" configuration and a reduction in magnesium concentration resulted in calcium sulfite platelets similar to those produced in many limestone FGD systems. The large platelets formed during the latter portion of this test settled well and clarifier and filter efficiencies were restored. Figure 9 is an electron micrograph of the platelet solids.

Reduced Reaction Tank Volume

The objective of the reduced reaction volume test was to assess system operability with the main reaction tank eliminated from the scrubbing loop. The system did remain operable with the major difference being increased oxidation in the reduced volume configuration

(Figure 8). This increased oxidation was thought to have been caused by liquid level control problems in the mixing well. At times, the upper agitator blade in the mixing well was exposed to the air causing a frothing effect which could have increased O_2 transfer into the slurry relative to normal operation. Other than this effect, operation with a small reaction tank volume was very similar to that with the normal reaction tank configuration.

Phase V—Chloride Addition Testing

The final test phase was devoted to determining the effect of increased chloride levels on system chemistry. $CaCl_2$ was added to the system to increase the chloride level from 10 mmole/liter (350 ppm) to 80 mmole/liter (2800 ppm). Since operating time was limited during this phase, the magnesium level was increased simultaneously to maintain system operability. A ratio of 1 mole of magnesium added for each 2 moles of chloride was found to maintain the scrubbing solution's liquid phase alkalinity. The results of Phase V testing are shown in Figure 10.

Since the magnesium concentration was increased in conjunction with the increase in chloride, extensive data concerning the independent effect of chloride are not available. However, data gathered early in this phase, before the system was at steady state, indicate the chloride effect. An initial spike in chloride concentration of 270 mmole/liter (9600 ppm) occurred. The results of
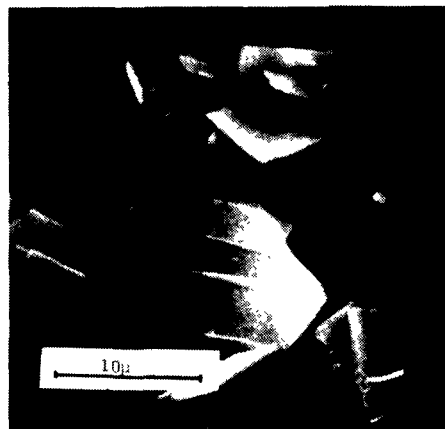

Figure 9. Calcium sulfite hemihydrate platelets formed during "no mixing well" test.

operating at this high chloride concentration were as expected. The calcium concentrations were higher than normal; an initial spike was noted in the oxidation rate; significant dissolution of solid phase calcium in the scrubber was evident; and scaling conditions were observed on the lower bed. As the chloride concentration in scrubbing slurry and the clarifier liquor equalized at about 80 mmole/liter (2800 ppm), the solid oxidation fraction dropped to below 0.1 and subsaturated conditions were again measured in lower bed effluent liquor. The need for calcium solids dissolution was eliminated as the magnesium/chloride ratio increased in the scrubber feed liquor.

As mentioned previously, the magnesium concentration was increased to offset the addition of chloride. Since a magnesium level of 125 mmole/liter (3000 ppm) had maintained system operability at the conclusion of Phase IV and since 1 mole of magnesium electrically balances 2 moles of chloride, the magnesium concentration was increased to about 160 mmole/liter to offset the 70 mmole/liter increase in chloride. Since the magnesium sulfite and carbonate salts are soluble, the liquid phase alkalinity was essentially the same in Phase V (after the initial spike in chloride) as during Phase IV. The low calcium dissolution rates in the scrubber measured between August 25 and 30 reflect this.

Solid Solution Chemistry

A major objective of this program was to determine the basis for the operation of the Paddy's Run system in a mode which was subsaturated with respect to gypsum. During the course of this program, the solid phase sulfate/total sulfur ratio was found to have a major impact on the gypsum saturation level in the system's reaction tank liquor. This same result was also found in a laboratory study previously conducted by Radian[1]. In Figure 11, the field data from the LG&E test program are compared with the correlation of solid phase sulfate/total sulfur versus gypsum relative saturation derived from the laboratory experiments. While there is scatter due to (1) unsteady-state operation, and (2) uncertainties in the gypsum relative saturations and analytical results in Phase I, the results from the field testing show that the reaction tank liquor remained subsaturated when the solid phase sulfate/total sulfur level remained below about 0.16.
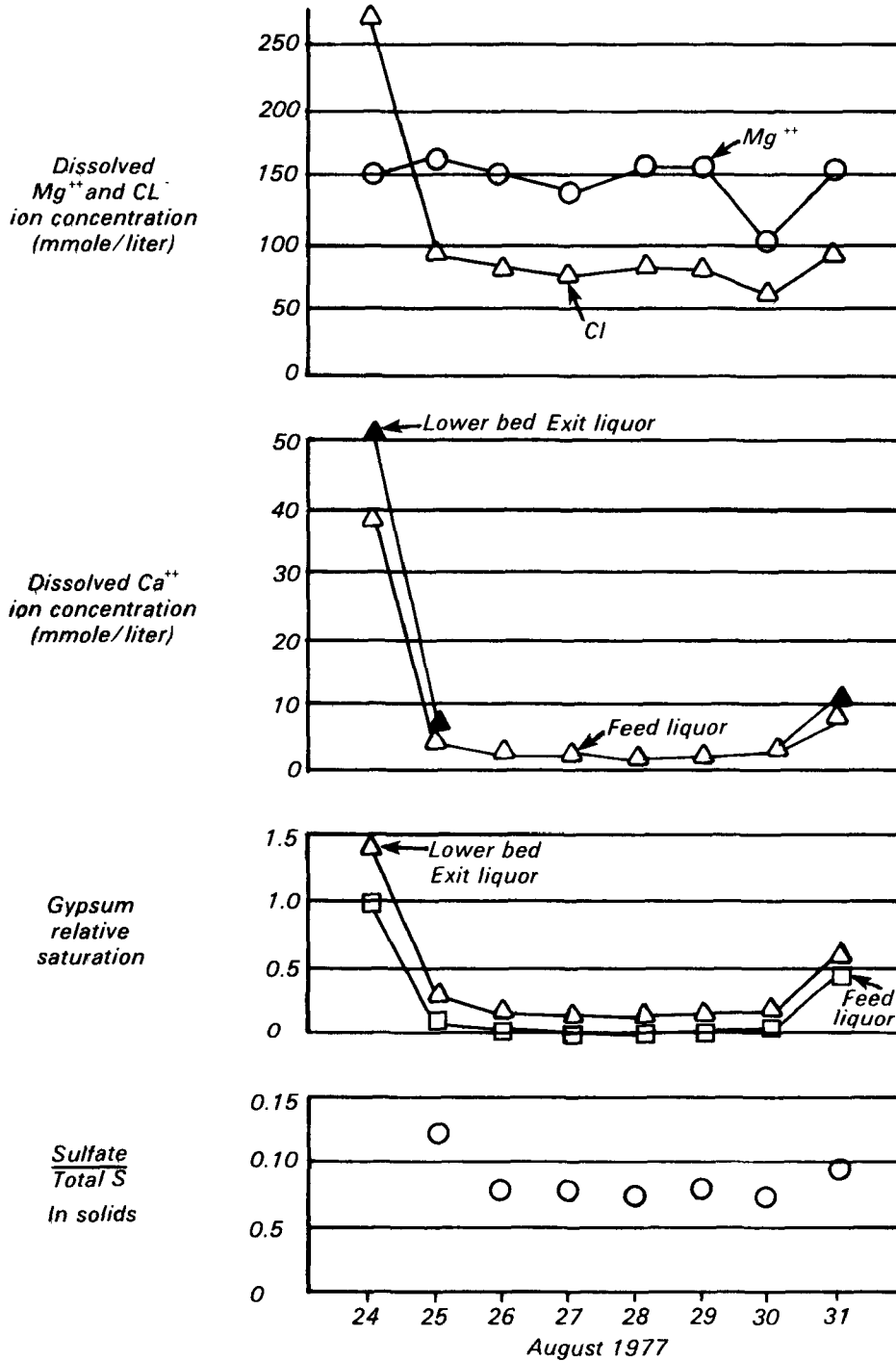
Figure 10. Phase V system chemistry parameters.

Conclusions

- Carbide lime contains oxidation inhibitors which allow the Paddy's Run system to operate in a scale-free mode. Without these oxidation inhibitors, testing with commercial lime resulted in gypsum scaling in the scrubber.

- Magnesium addition markedly improved SO_2 removal efficiency by increasing the liquid phase alkalinity (98 percent removal at ~3000 ppm Mg^{++} with low chloride levels).

- Addition of magnesium (~3000 ppm) enabled the Paddy's Run commercial lime system to operate without scaling by (1) reducing the sulfite oxidation fraction, and (2) reducing the amount of calcium sulfite dissolution which occurred in the scrubber.

- Extremely high sulfate magnesium concentrations (~4000 ppm Mg^{++} with low chloride levels) resulted in the formation of solid crystals with poor settling/dewatering characteristics.

- An increase in chloride tended to increase sulfite oxidation and the tendency to scale. Magnesium addition can offset this effect.

- Lime systems can function with low reaction tank residence times due to the rapid dissolution of lime. The size of the reaction tank and the lime addition point location can affect the crystal structure.

References

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2. Holcombe, L. J. and K. W Luke. Characterization of Carbide Lime to Identify Sulfite Oxidation Inhibitors, EPA-600/7-78-176 (NTIS PB286646). September 1978.
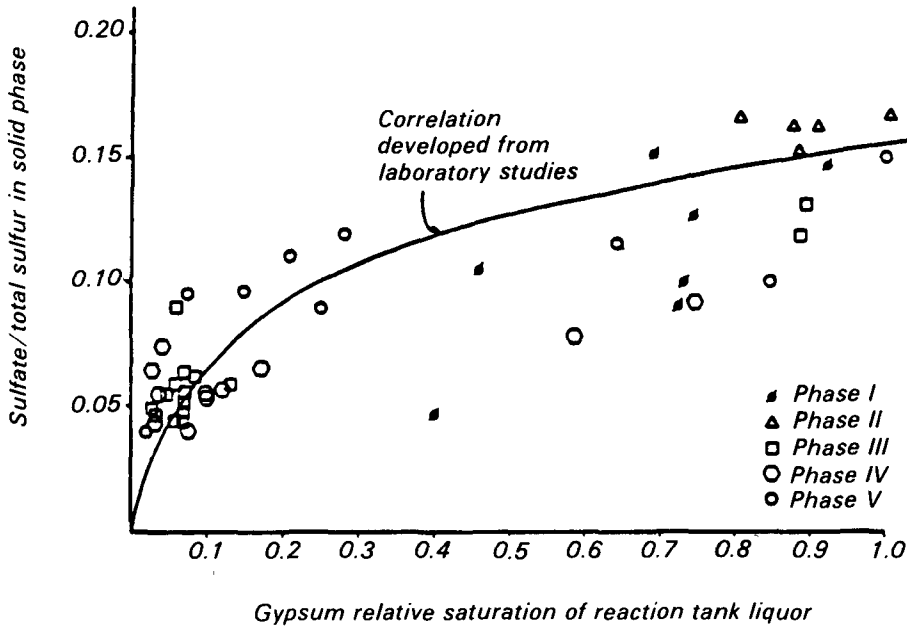
Figure 11. Comparison of LG&E field data with laboratory solid solution test results.

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