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**"NONEQUILIBRIUM SULFUR CAPTURE & RETENTION IN  
AN AIR COOLED SLAGGING COAL COMBUSTOR**

**Third Quarterly Technical Progress Report**

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## 1. SUMMARY

The objective of this 24 month project is to determine the degree of sulfur retention in slag in a full scale cyclone coal combustor. This effort will consist of a series of up to 20 parametric tests in a 20 MMBtu/hr slagging, air cooled, cyclone combustor. During the present quarterly reporting period ending June 30, 1996, the first two tests in this project were implemented. In addition, a total of 14 test days were completed during this quarter on the parallel project that utilizes the same 20 MMBtu/hr combustor. Some of the sulfur retention in slag results of that project have a direct bearing on this project, and they will be briefly summarized in this report.

The two tests completed in this project were part of the first test series in which calcium sulfate in the form of gypsum or plaster of Paris were injected into the combustor.

The results of the gypsum test were not satisfactory. The high water concentration in the gypsum reduced the concentration of calcium sulfate to 68.8%. Stack measurements of SO<sub>2</sub> indicated that 70% of the sulfur in the gypsum evolved into the combustion gases. It was assumed that this was due to the high concentration of water in the gypsum which on evaporation in the combustor broke up gypsum particles and evolved the sulfur into the combustion gases. In addition, slagging was very poor when the gypsum was injected.

Consequently, in the second test, plaster of Paris (p.o.p.), CaSO<sub>4</sub> · 0.5H<sub>2</sub>O, was injected. Here the water concentration is only 6.2% by weight. Coal with a 12.2% ash content and 2.57% sulfur was injected in addition to 120 lb/hr of limestone for slag conditioning. In the second test condition, additional 136 lb/hr of plaster of Paris was injected. Based on the stack SO<sub>2</sub> measurements, only 12% of the sulfur in the plaster of Paris was released into the gas phase in the combustor. However, here again slagging became very poor with the addition of p.o.p. Based on decreases in the combustor wall temperature, it was deduced that the calcium sulfate from the p.o.p. was depositing as slag on the combustor walls and remaining on the wall. Only 6.7% of the combined coal and p.o.p. sulfur remained in the slag sampled from the flow out of the slag tap. Also, the grab samples of fly ash in the baghouse yielded only 4.5% sulfur concentration. This was much less than the anticipated concentration from the stack SO<sub>2</sub> measurement.

To prevent plugging of the slag tap, the injection period of p.o.p. was limited to a little over 1 hour. It is possible that the sulfur from the injected p.o.p. accumulated in the cooler upstream end of the combustor wall and gradually released after the injection of p.o.p. ceased. This gradual release could have been verified with continuous monitoring of the stack SO<sub>2</sub>. However, this was possible with the present stack gas sampling system.

As is well known, the solubility of sulfur in coal slags is very low and the slag must be removed from the combustor within a few minutes. Therefore, the poor slagging with the injection of calcium sulfate was unexpected. This effect could be due to the impact of calcium sulfate in substantially increasing the slag viscosity. It could also be due to the mode of injection of the p.o.p., i.e. poor mixing and wall deposition. To correct the first possibility, the coal ash mass flow rate can be increased relative to the calcium sulfate concentration. This has the added benefit in reducing the relative sulfur concentration in the slag which limits the sulfur re-evolution.

To correct for the second possibility, several different off axis injection procedures are being tested. These changes will be implemented in the next quarter.

From the 14 concurrent tests in the other project, it was observed that the sulfur concentration in the slag removed from the combustor was substantially higher than in previous tests with the earlier design of this 20 MMBtu/hr combustor. Sulfur concentrations approaching 20% were measured in the slag in one tests. This compares with less than 11% sulfur in the best test in the earlier combustor. Of even greater significance is the observation that over 95% of the slag was removed through the slag tap in the combustor. In the earlier, shorter unit, only about one-third of the slag was removed through the tap. The balance flowed out of the exit nozzle into the boiler, which was an unacceptable situation for a commercial unit.

In conclusion, the new combustor is operating much better than the prior unit. The conditions needed to high slag retention and high sulfur retention in the slag in the combustor have been established. The only unexpected result, the poor slagging with high injection rates of calcium sulfate can be corrected by increasing the coal ash mass flow rate and/or by optimizing the injection method. This will be the focus of the work in the next quarter.

## 2. PROJECT DESCRIPTION

### 2.1. Objectives

The primary project objective is to determine the degree of sulfur retention in slag in a full scale cyclone coal combustor. This non-equilibrium process is a key step in the capture and retention of sulfur released during coal combustion by the interaction with calcium based sorbent particles. By encapsulating the sulfur bearing calcium particles in slag, the need for landfilling of this waste is eliminated. This objective will be implemented through a series of up to 20 one day tests carried out in a 20 MMBtu/hr air cooled, slagging combustor-boiler installation located in Philadelphia, PA. The project will consist of two tasks. Task 1 consist of the experiments conducted in the 20 MMBtu/hr combustor, and task 2 will consist of analysis of this data. All the operating procedures for this effort have been developed in the 7 years of operation of this combustor.

### 2.2. Technical Approach

#### 2.2.1. Overview of the Work

The work of this Phase 3 project will be implemented on Coal Tech's patented, 20 MMBtu/hr, air cooled cyclone coal combustor that is being installed on an oil designed, package boiler at a new facility at the Arsenal Business Center in Philadelphia, PA. This new facility consists of a refurbished and upgraded 20 MMBtu/hr combustor that had been tested at a manufacturing plant in Williamsport, PA from 1987 through 1993. The primary fuel has been, and will remain, coal. Other tests, including combustion of refuse derived fuels and vitrification of fly ash, have been successfully performed. Additional ash injection may be required to achieve high sulfur retention in the slag in the present combustor tests.

The combustor's novel features are air cooling and internal control of  $\text{SO}_2$ ,  $\text{NO}_x$ , and particulates. Air cooling, which regenerates the heat losses in the combustor, results in a higher efficiency and more compact combustor than similar water cooled combustors. Internal control of pollutants is accomplished by creating a high swirl in the combustor which traps most of the mineral matter injected in the combustor and converts it to a liquid slag that is removed from the floor of the combustor.

$\text{SO}_2$  is controlled by injecting calcium oxide based sorbents into the combustor to react with sulfur emitted during combustion. The spent sorbent is dissolved in the slag and removed with it, thereby encapsulating the sulfur in slag. Part of the sorbent exits the combustor with the combustion products into the boiler where it can react with the sulfur. The primary objective of the present tests is to maximize the degree of sulfur retention in the slag. All spent sorbent not reporting to the slag is either deposits in the boiler or it is removed in the stack particle scrubber.

$\text{NO}_x$  is controlled by staged, fuel rich combustion inside the combustor. Additional reductions are achievable by reburning in the boiler or by ammonia injection if the stack gases.

Excellent progress had been made prior to the start of the present project in meeting several of these combustor performance objectives. One of the most important objectives of this technology development effort is to demonstrate very high SO<sub>2</sub> reduction in the combustor. Prior to the start of the present project, the peak SO<sub>2</sub> reduction achieved with sorbent injection in the combustor had been 90%. Of this amount a maximum of 11% of the total coal sulfur was trapped in the slag. Evaluation of this prior data indicated that the low sulfur retention in the slag was due to excessive slag residence time in the combustor. Since the solubility of sulfur in slag is low, long slag residence times (in excess of 5 minutes) can result in substantial sulfur gas re-evolution into the gas phase.

To reduce the slag time in the combustor in the present project tests, the slag mass flow rate will be increased by either using very high ash coals or by injection coal ash with the coal. High ash mass flow rates increase the slag flow rate.

In order to determine the non-equilibrium sulfur-slag chemistry, calcium sulfate (anhydrite) will be injected into the combustor to vary the slag flow rate inside the combustor and to measure the sulfur gas evolution rate independently of the calcium-sulfur heterogeneous capture reaction. This information will then be used to measure the combined sorbent-sulfur capture rate in the gas phase with the sulfur retention rate in the slag inside the combustor.

The 20 tests planned for this project will allow full parametric variation of these sulfur-sorbent capture and sulfur-slag re-evolution reactions.

### 2.2.2. Task Description

#### Task 1: Sulfur Chemistry Tests in the Slag of a Cyclone Combustor.

This task will consist of four groups of tests designed to validate the sulfur chemistry in slag under non-equilibrium conditions. The tests are designed to validate the chemical and fluid mechanical processes occurring in the capture and retention of sulfur in slag. These reactions are based on prior analytical and experimental work in coal slags and coal like slags, such as steel blast furnace slags. The plan calls for a total of 20 one day tests. However, due to resource limitations, it is planned to accomplish the project objectives in as few as 15 one day tests. To meet all the parametric test variations, the duration of individual test conditions will be reduced.

In the first group of six tests, calcium sulfate as gypsum or plaster of Paris will be injected into the 20 MMBtu/hr combustor at a rate that duplicates the complete reaction of sulfur from a **2% sulfur** coal with calcined calcium oxide particles. While maintaining this sulfur concentration fixed, the total slag mass flow rate will be increased in discrete steps, with each step remaining fixed for a specific period. The purpose of these tests and the second group of tests is to measure sulfur re-evolution from a sulfur based calcium compound at concentrations that duplicate the maximum amount of sulfur that can be captured in the combustor with calcium oxide sorbents.

In the second group of six tests, calcium sulfate will be injected into the 20 MMBtu/hr combustor at a rate that duplicates the complete reaction of sulfur from a **4% sulfur** coal with



calcined calcium oxide particles. While maintaining this sulfur concentration fixed, the total slag mass flow rate will be increased in discrete steps, with each step remaining fixed for a specific period.

These two groups of tests will determine the sulfur retention capability of slag as a function of slag residence time in a commercial scale combustor, namely the unit rated at 20 MMBtu/hr. In other words these tests will focus only on the sulfur retention in slag. This type of test was performed briefly in the 20 MMBtu/hr combustor facility and the results indicated that this is an effective method for studying sulfur retention in slagging cyclone combustors.

In the third group of four tests, the entire sulfur capture process will be implemented from the injection of the uncalcined sorbent to its reaction in the combustor and impact and removal with the slag. The slag mass flow rate will be adjusted to duplicate the optimum slag flow rate determined from the group one tests. These fuel rich and fuel lean tests will serve to validate the entire sulfur capture and retention process in the combustor.

In the final group of four one day tests, reacted sorbent collected in the boiler and stack baghouse will be injected into the combustor at the optimum slag mass flow rate determined from the first two groups of tests. The objective of this test series will be to determine the degree of sulfur encapsulation in slag in cases where the magnitude of sulfur capture with injection of sorbent in the combustor is insufficient to meet environmental emission standards.

All the experiments will be conducted in accordance with the procedures developed in the seven years of testing in Williamsport and in the current tests in Philadelphia on the 20 MMBtu/hr combustor.

#### Task 2: Analysis

The results of the tests in task 2 will be analyzed using two and three dimensional combustion codes for the conditions existing in this combustor, and a code for analyzing slag flow on the walls of the combustor. The results will be compared with prior tests in the present combustor and with laboratory scale data on the sulfur chemistry process in coal and steel slags.

The analytical procedures and bench scale tests on sulfur-slag reactions developed in prior decades will be used for this purpose.

### 3. PROJECT STATUS

#### 3.1. Effort of the Present Quarter

The implementation of the work on this project involves testing on Coal Tech's 20 MMBtu/hr slagging coal combustor-boiler test facility. A second generation combustor was installed at a new facility in Philadelphia in 1995 and it became operational at the end of 1995. Initial shakedown tests on this combustor were implemented in the first quarter of calendar year 1996. These tests consisted of clean fuel firing with limited coal firing without slagging operation. At the end of March, a series of coal fired tests under slagging conditions were implemented. They established the performance level of the new combustor. A total of 14 days of tests under slagging conditions were successfully implemented in the second quarter of 1996.

An important part of the tests for the present project is to measure the SO<sub>2</sub> concentration in the stack under the various operating conditions required for this project. While the stack sampling equipment was operational in April, the calibration gases needed to calibrate the stack gas instruments were not delivered until mid-May. Therefore, by mid-May, the combustor facility was ready for the initiation of the test effort under the present project. The first two tests in the present project were then implemented in this quarter.

3.1.1. Test No.1: The first test under the present project was performed on May 21, 1996. The plan for the initial test series was to determine the sulfur retention capability of sorbent bearing slag. To accomplish this calcium sulfate in the form of gypsum or plaster of Paris was to be injected into the combustor with the coal. For the May 21 test, agricultural gypsum powder, consisting of 68.8% calcium sulfate (by weight), 87% gypsum; (CaSO<sub>4</sub>·2H<sub>2</sub>O), with the balance water, was used. During the gypsum injection period, the coal feed rate averaged 900 lb/hr, equal to 10.4 MMBtu/hr, plus 0.8 MMBtu/hr of gas. The sulfur content of the coal averaged 2.7%, or 24.3 lb/hr. The stack SO<sub>2</sub> measurement was 770 ppm at 11.8% oxygen by volume. A 100% conversion of coal sulfur to SO<sub>2</sub> would result in a SO<sub>2</sub> level of about 1200 ppm. The SO<sub>2</sub> was measured in a pulsed fluorescence instrument, which was calibrated against a known concentration of SO<sub>2</sub> (508 ppm) in nitrogen. The readings must be corrected by a factor of 1.38 to account for collisional de-excitation by O<sub>2</sub>, CO<sub>2</sub>, CO, and H<sub>2</sub>O. Thus the corrected level of SO<sub>2</sub> was 1060 ppm. On this basis almost all the coal sulfur was converted to SO<sub>2</sub>. [Note: To verify the accuracy of this correction factor, a calibration gas of 500 ppm SO<sub>2</sub> in dry air is planned in the near future.]

[Note: The pre-test calibration of the coal feeder was performed by collecting a sample from the coal feeder for a period of several minutes and weighing it. This yielded a feed rate of 1020 #/h. This calibration was performed with the coal feeder on manual setting. In June, the feeder was recalibrated for automatic computer control, and it yielded a somewhat different calibration curve. It was therefore decided to recalibrate the manual setting, but to increase the sampling period. This yielded about 10% lower feed rates, which is attributed to variations in the level of coal in the transfer bin above the feeder. As a result, the May test was performed at a 12% lower feed rate than had been planned.]

In addition about 100 lb/hr of limestone was injected to condition the slag. Attempts to lower this limestone level during the gypsum injection yielded very poor slagging.

At the above condition, gypsum at the rate of 230 lb/hr was mixed with the coal and injected into the combustor. This added 37 lb/hr of sulfur to the combustor, in addition to the 24.3 lb of sulfur from the coal, for a total of 61.3 lb/hr of sulfur. The stack SO<sub>2</sub> level rose to 1700 ppm at O<sub>2</sub> of 12% by volume. Applying the 1.38 correction factor yields an SO<sub>2</sub> of 2346 ppm.

Based on the coal only sulfur content and the gypsum sulfur content, the SO<sub>2</sub> level in the stack should have been 3030 ppm if all the sulfur from both the coal and gypsum was converted to SO<sub>2</sub>. The 1700 ppm SO<sub>2</sub> level indicates that about 70% of the sulfur in the gypsum was released as SO<sub>2</sub>. This is obtained by subtracting the coal only results from the gypsum results. It shows that a substantial part of the sulfur in the gypsum was evolving as SO<sub>2</sub>. However, slagging was very poor which yields a long residence time of the CaSO<sub>4</sub> in the slag. The sulfur will evolve from the slag because sulfur has a low solubility in slag.

Consequently, the gypsum was turned off and the limestone level increased to re-establish good slag conditions. The gypsum was turned on again to 178 lb/hr, containing 28.6 lb/hr of sulfur, for a total of 52.9 lb/hr of sulfur, including the coal. The stack SO<sub>2</sub> level increased from 745 ppm (corrected to 1028 ppm) for coal-and limestone to 1130 ppm (corrected to 1559 ppm) with the gypsum, at 11% O<sub>2</sub>. If all the sulfur were converted to SO<sub>2</sub>, the concentration would have been 2615 ppm. This indicates that only 37% of the sulfur in the gypsum was released as SO<sub>2</sub>.

Slag samples were collected for each operating conditions. Post test analysis of the samples showed that generally small concentrations of sulfur in the slag with no correlation to the injected sulfur. The sulfur content as a function of the ash in the coal ranged from under 1% to a high of 7.64% for the base case without gypsum. It is concluded that the generally poor slagging in this test resulted in unfavorable conditions for sulfur retention in slag.

There was no real time sampling setup for removal of fly ash upstream of the baghouse. Consequently, a mass balance of the sulfur in the system could not be made.

The test began at 8 AM with initial oil/gas heatup, and it continued until 4:10 PM.

Conclusions from Test No. 1. The poor slagging of the gypsum prevented meaningful results from this tests. This was attributed in part to the high water content of the garden gypsum. It was therefore planned to perform the next test with plaster of Paris, in which the calcium sulfate is 92% by weight compared to 68% in the gypsum.

3.1.2. Test No. 2: The next test was performed with Plaster of Paris (p.o.p.), in which the calcium sulfate is 92% by weight compared to 68% in the gypsum. This test was performed on June 28, 1996. About 136 #/hr of p.o.p. was injected into the combustor with 980 #/hr of 2.57% sulfur coal.

An unexpected result of this test was that the p.o.p's CaSO<sub>4</sub> that was deposited on the walls appeared to inhibit slag flow out of the combustor. This effect was even more pronounced than in the prior gypsum injection test. To inhibit slag flow, the calcium sulfate must increase the slag viscosity. This is the opposite effect that calcium carbonate or hydrate have. Both of them flux the slag, i.e. lower the viscosity of acid type coal ash, at similar concentrations. If this effect is confirmed in future tests, it will have a major impact on this project's key objective of sulfur retention in slag. As is well known, the solubility of sulfur in slag is very low, and the slag must be removed from the combustor within minutes to prevent sulfur re-evolution. Therefore, to maintain rapid slag flow, it will be necessary to increase the coal ash concentration and minimize the calcium sulfate concentration. This was one of the approaches noted in this project proposal, where it was stated that at high ash concentrations less than 10% sulfur concentration in the slag will allow retention of all sulfur in high sulfur coal. While high ash concentrations tests are planned, additional tests with calcium sulfate injection are planned first to clarify the impact of this compound on slag viscosity and slag flow.

The details of the June 28 test are as follows:

The coal tested had a 2.57% sulfur content and about 12.2% ash. At 980 #/hr of coal, the ash content was 120 #/h. The concentration of injected CaSO<sub>4</sub> was 128 #/h (136#/hr of p.o.p.). In addition, 120#/h of limestone was injected, resulting a maximum of 67 #/h of CaO in the slag. The limestone was injected because slag flow out of the combustor essentially ceased when it was substantially reduced. Also, analysis showed that part of the slag contained refractory liner material. From a materials balance, it was determined that about 72% of the injected mineral matter, (excluding any sulfates) were retained as slag, which either remained deposited on the combustor walls after the end of the test or was drained through the combustor's slag tap. A substantial quantity of slag remained on the wall due to the poor slagging of the injected p.o.p.

The SO<sub>2</sub> concentration was measured in the stack at the boiler outlet with coal and limestone injection only, and with the addition of the p.o.p. One problem experienced was drifting of the instrument. Consequently, a linear approximation had to be made for the instrument measurement against the calibration gas of 508 ppm of SO<sub>2</sub> in nitrogen. In addition, as noted above a further correction factor of about 1.38 had to be made for combustion gas quenching of SO<sub>2</sub>. As a result, the measured SO<sub>2</sub> concentration of 270 ppm without p.o.p, and 330 ppm with p.o.p was corrected to **583 ppm** and **712 ppm**, respectively. If all the coal sulfur had been converted to SO<sub>2</sub>, the concentration would have been **1356 ppm**. With the addition of the sulfur in p.o.p., the concentration would have increased to **2461 ppm**. Therefore, **57%** of the sulfur injected during the coal/limestone test condition, and **71%** of the sulfur for the plaster of Paris test condition, was either retained in the slag or in the ash collected in the boiler floor or baghouse.

Of even greater interest is that apparently only 12% of the sulfur in the p.o.p. was released into the gas phase, as determined from the stack gas sampling. However, as noted above, slagging was very poor, and most of the injected p.o.p. remained on the combustor walls. Due to poor slagging which can lead to blockage of the slag tap, the injection of the p.o.p. was limited to a little over one hour. Therefore, the SO<sub>2</sub> in the p.o.p. on the combustor wall could have been released after injection ceased.

The combustor slag and stack ash samples were analyzed for both test conditions. The raw data showed that 0.45% of sulfur was retained in the slag for the coal and limestone case, and 1.45% sulfur was retained when p.o.p. was added. As a rough estimate, the slag retention as a percent of total injected mineral matter was 75%. From a chemical analysis of the slag, it was determined the 18% and 13% of the slag consisted of dissolved combustor liner material for the two cases, respectively. Therefore, from an approximate mass balance of injected sulfur and mineral matter, it was computed that 2.7% of the coal sulfur remained in the slag for the first case, and 6.7% of the sulfur remained in the slag in the second case, i.e. the one with p.o.p. injection.

The sulfur concentration of the fly ash collected in the baghouse, which was sampled at the same time as the slag samples, showed that the sulfur content was 2.8% of the fly ash sample for the first case, 4.5% of the fly ash in the second case. Removing the CaO concentration from the fly ash, increases these values to 3.7% and 6.4% respectively. Combining the sulfur in the slag and fly ash yields a total concentration that is substantially less than anticipated from the stack gas SO<sub>2</sub> measurement.

This result is based on the assumption that the various injected mineral streams partition equally in the slag, boiler floor, and baghouse. However, due to different particle size distributions of the various materials, equal partitioning is not to be expected. Partitioning can be determined from the ratio of silica, the major constituent of coal ash, to the calcium oxide ratio in the slag and baghouse fly ash. Based on injected material, this ratio should have been 78% for the first case, and 43% for the second case. The measured values for the slag were 53% and 44%, respectively. The corresponding values for the baghouse ash were 130% and 86%. These results indicate that the CaO from the limestone and p.o.p. preferentially reported to the slag, while the coal ash was preferentially carried out to the stack.

The above data show that the sulfur concentration in the slag was enhanced by the presence of the injected plaster of Paris. However, the sulfur content in the slag or stack fly ash was far less than anticipated from the stack SO<sub>2</sub> measurements. In view of the poor slagging obtained with the injected p.o.p., high sulfur retention in the slag is not expected. This is due to the low sulfur solubility in slag. On the other hand the low sulfur concentration in the slag with only limestone injection was anticipated because limestone is not an efficient sulfur sorbent in the combustor. Clearly, the next step is to improve the slagging in the combustor in the presence of CaSO<sub>4</sub> injection. One way of accomplishing this is to optimize the injection method. Another is to increase the ratio of coal ash injected to the p.o.p. injected. In that case, the impact of the latter on slag viscosity will be reduced. Work on both approaches is planned for the next quarter.

### 3.2. Summary of Slag Retention, SO<sub>2</sub> Reduction, and Sulfur in Slag from the Concurrent 20 MMBtu/hr Project.

In view of the importance of slag retention and sulfur retention in the slag in the combustor, a brief summary of pertinent results obtained in the other project with the 20 MMBtu/hr combustor during this period will be given.

Figure 1 shows the slag removed through the slag tap as a percentage of the coal ash and calcium oxide sorbent injected into the combustor. This data applies to 9 of the 16 tests conducted in this period. These slag data also include liner material that was dissolved by the slag from the combustor wall. The liner material in the slag is determined from slag sampling chemical analysis. Note that in some tests the slag removed through the tap is low. However, in these tests much of the missing slag remains on the combustor wall. This was verified by post test measurements of the inner combustor dimensions. In figure 1, test number "g", the amount of fly ash collected in the baghouse is added to the slag removed. The number less than 100%. Some of the missing mineral matter is deposited on the liner of the combustor, as fly ash on the boiler floor, and in calibration errors in the amounts injected. Also, it was noted after these data were plotted that an 8% to 15% overestimate of the coal feed rate was detected in the coal feeder calibration. The data in figure 1 are based on the original coal feed rate calibration. Therefore, the slag retention is actually about 10% higher. [It is not 15% because the coal ash is only a majority, not 100% of the injected minerals.] Therefore, the estimated average mineral matter retention in the combustor is between 65% and 75

The really important result from figure 1 is obtained by comparing it with figure 2. This figure 2 shows the slag retention in this combustor's previous design as used in Williamsport. The data was obtained in 1993 when the original combustor had been optimized. Note that while slag retention also averaged 65% to 70%, over 50% of this slag flowed into the boiler out of the combustor exit nozzle. Only an average of 20% was removed through the slag tap. This compares with the results in figure 1. This is a key advantage of the present combustor.

As noted in all tests, limestone was injected with the coal for slag conditioning. For a number of operational reasons, only limited tests on calcium hydrate injection in the combustor were performed in this quarter. SO<sub>2</sub> reductions with limestone injection is not as effective, as has been reported on many occasions during the Williamsport tests. The tests have been performed with about 2.75% sulfur coal.

Figure 3 shows the percentage of the sulfur in the slag as a percentage of the total sulfur in the coal. Again these figures should be increased by 8% to 15% due to the correction in the coal feeder rate measured in July 1996. Note that this graph does not show the absolute amount of the total sulfur in the coal that reports to the slag, it only shows the ratio of sulfur in the slag to the ratio of sulfur in the coal. To estimate the ratio of the total sulfur that reports to the slag, these data need to be reduced by at least 25% because only 3/4 on average of the coal ash is retained in the combustor slag. In any case, the data show that as much as 20% of the total coal sulfur is retained in the slag in one of the tests. This is twice as high as the maximum of 11% measured in the prior combustor tests. 10% is also the maximum reported elsewhere to the best of the author's knowledge.

Similarly, figure 4 shows the percentage of sulfur in the baghouse fly ash as a percentage of the total ash in the coal. Here it is assumed that all the ash reports to the stack. In fact only about 1/4 to 1/3 of the coal ash reports to the stack. This indicates that a maximum of 10% of the total coal sulfur reported to the baghouse ash.

Figure 5 shows the percent SO<sub>2</sub> reduction in the combustor for the May/June tests with limestone injection. Also shown are two tests with hydrate injection into the boiler. To repeat, these data were taken with the pulsed fluorescence instrument, which according to the manufacturer requires a correction factor which depends on the concentration of O<sub>2</sub>, CO<sub>2</sub>, CO, and the nature of the calibration gas. In the results reported for the Williamsport combustor tests this correction factor which generally equals 1.35 to 1.38 was used to increase the measured SO<sub>2</sub> data when the calibration gas was 500 ppm SO<sub>2</sub> in nitrogen, as opposed to air. It is planned to recalibrate the instrument with SO<sub>2</sub> in air. If sustained on recalibration, then the data in figure 3 should be reduced by about 1/4.

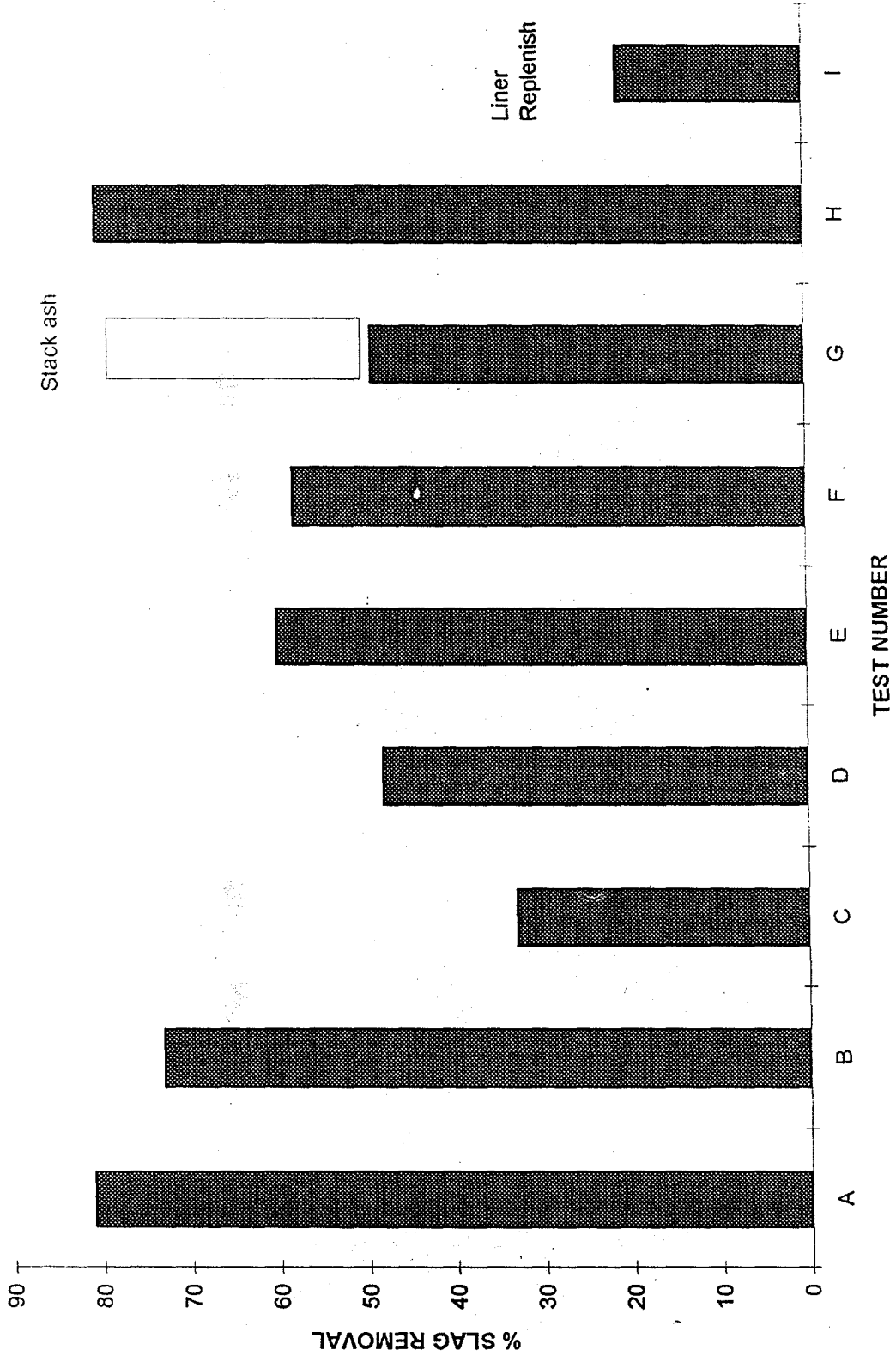
In any case, the data in figure 5 shows that substantial SO<sub>2</sub> reductions were obtained with limestone, which based on prior tests in Williamsport is about 1/3 as effective as hydrate. On the other hand, the calcium hydrate injection in the boiler is very effective. This test was performed to determine if the stringent SO<sub>2</sub> standards for Philadelphia, namely 0.5 lb/MMBtu could be met with sorbent was injected into the boiler when using a high sulfur coal. The uncorrected 70% SO<sub>2</sub> reduction in the 2.75% sulfur coal to about 1.2 lb/MMBtu appears to be outside the range necessary. However, note that the main objective of these tests is at present reliable combustor operation. Therefore, no attempt at optimizing emission performance was made, especially since these tests are still classified as shakedown. If the standard cannot be met with this coal, then the option remains to return to 1.2% sulfur coal, where only 72% SO<sub>2</sub> reduction is needed to meet the standard.

#### 4. EFFORT OF THE NEXT QUARTER

In the next quarter, additional tests with plaster of Paris injection into the combustor are planned. The objective of these tests will be to achieve good slag flow in the combustor with calcium sulfate injection in order to achieve the conditions at which sulfur re-evolution from the slag is inhibited. This will be accomplished by utilizing different injection methods, and by increasing the concentration of injected coal ash. This will dilute the impact of the CaSO<sub>4</sub> on slag viscosity. Based on the results to date, it is anticipated that improved sulfur retention will be achieved.

Slag Ret.

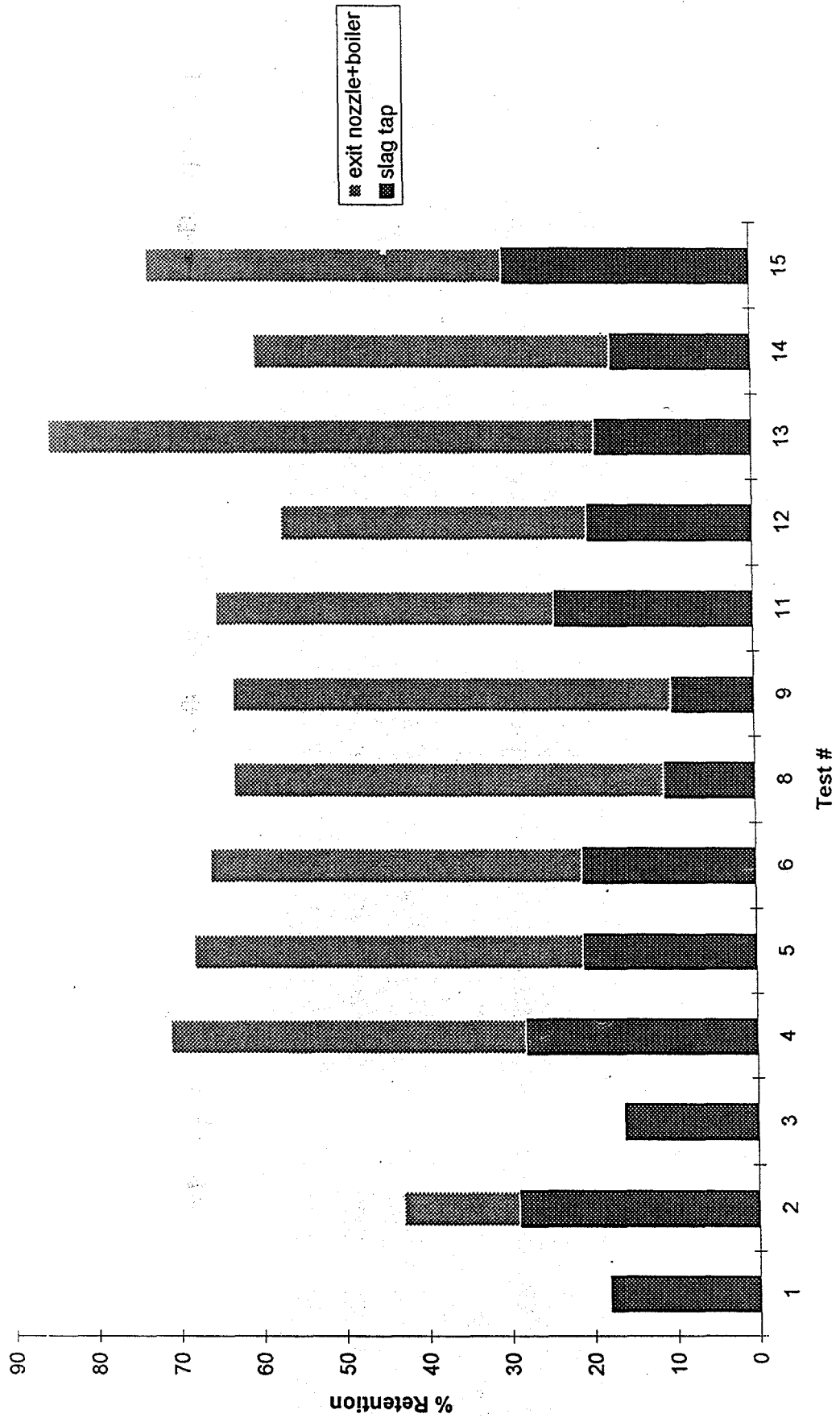
1) % OF COAL ASH + CaO REMOVED AS SLAG FROM COMBUSTOR TAP  
Est. Ave. Retention- 65 to 75%





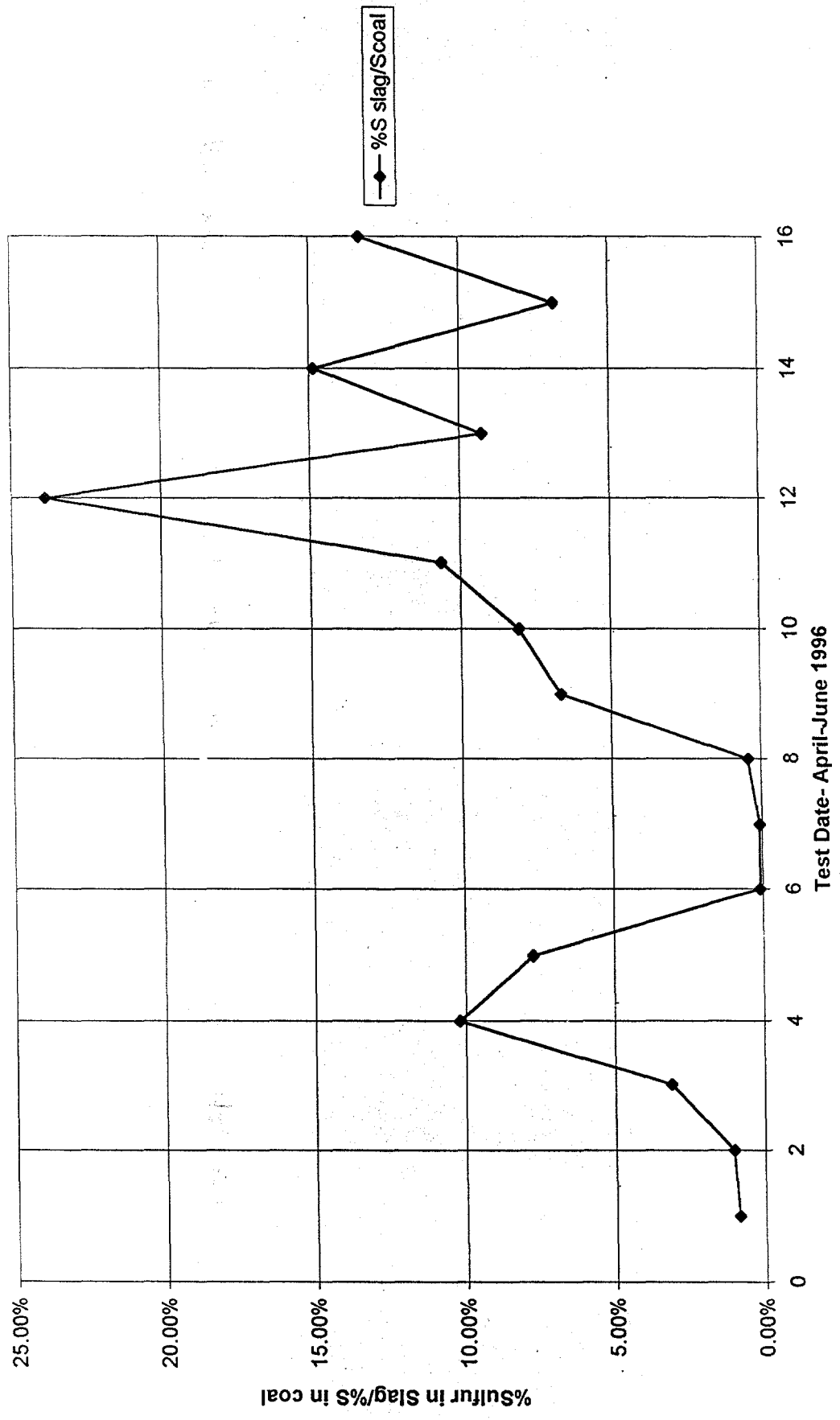
Slag Ret

2) Slag Retention in Combustor-1993 Tests



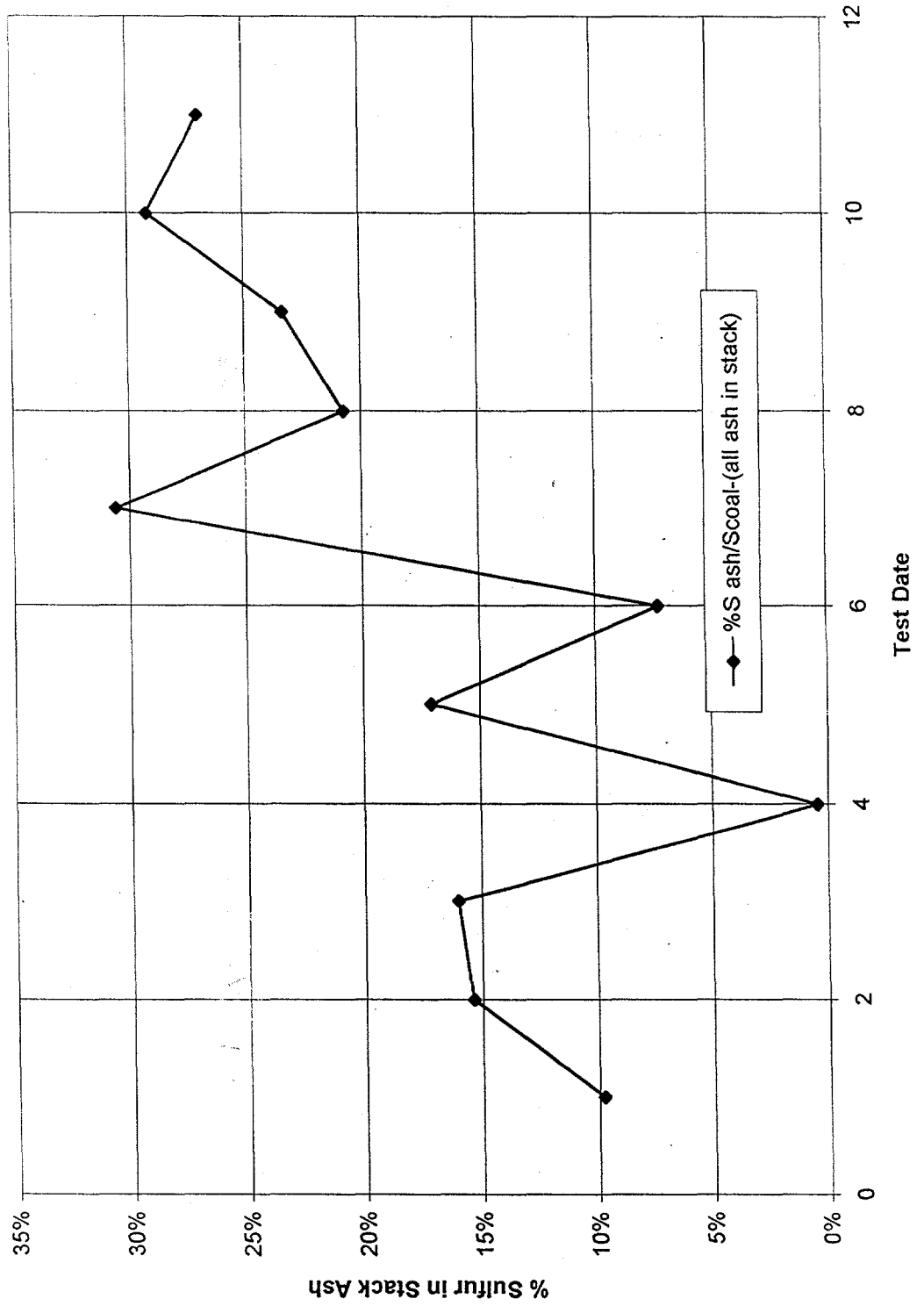
\$S in Slag

### 3) S in Slag/S in Coal vs Test Date (w/o Liner Loss)



%S in Ash

4) % Sulfur in Stack Ash/% S in Coal vs Test Date



5) SO<sub>2</sub> Reduction vs Ca/S Mol Ratio of Sorbent Injection  
May/June 1996 Tests

