FINAL TECHNICAL REPORT

September 1, 1988 through April 30, 1989

ICCI Project Number: 88/2.1A-7CS
Project Title: Furnace Sorbent Reactivity Testing for Control of SO_2 Emissions from Illinois Coals
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Abstract

Research was undertaken to evaluate the potential of furnace sorbent injection (FSI) for SO_2 emission control on coal fired boilers utilizing coals indigenous to the State of Illinois. Tests were run using four coals from the Illinois Basin and six sorbents, including one provided by the Illinois State Geological Survey (ISGS).

Testing was divided into three tasks:

1. Pilot- and bench-scale sorbent reactivity testing.
2. Sorbent microstructure characterization.
3. Injection ash characterization.

Pilot scale FSI testing gave SO_2 removal percentages greater than 60 percent with some tests (including those with the ISGS sorbent) exceeding 70 percent removal for Ca/S ratios of 2. Bench scale testing of injection at economizer temperatures yielded comparable removals of approximately 55 percent. X-Ray Diffraction tests showed a correlation between three measured parameters (average column length, modal column length and strain at maximum column length) and sorbent reactivity in the FSI tests. EP Toxicity tests for the sorbent injection ash gave values well below RCRA limits for regulated metals.

EXECUTIVE SUMMARY

Testing in the IFR with all four coals and six sorbents was completed. Sulfur removals in excess of 60 percent at a Ca/S ratio of 2 were noted for most tests. Tests with the lignosulfonate modified Marblehead calcium hydroxide and the ISGS alcohol hydrate gave sulfur removals above 70 percent under the same conditions. Removal percentages were lower for the coal IBCSP #2 than for the other coals. This was attributed to its higher pyritic to organic sulfur ratio.

Bench scale testing of reactivity at economizer temperatures yielded removals of roughly 55 percent at a Ca/S of 2. Studies were impacted by apparent mass transfer limitations on the rate of reaction.

X-Ray Diffraction tests of the sorbents focused on 8 parameters of their microstructure and three of these parameters (average column length, modal column length and strain at maximum column length) were found to correlate strongly with the sorbents' performance in the IFR testing. This may allow a method of predicting sorbent reactivity without costly pilot scale testing.

Analyses of sorbent injection ash for potential leachability using the EP Toxicity tests gave values well below RCRA limits for all metals tested. While below RCRA limits, the final pH values for these leachates were high enough to elicit concern.

SECTION 1

OBJECTIVES

The primary objective of the planned research has been to evaluate furnace sorbent injection (FSI) as a potential SO_2 emission control technology for coal fired boilers burning Illinois Basin coals. FSI offers the benefits of being less capital intensive than wet FGD as well as the ability to be readily retrofitted to existing facilities with space considerations. To evaluate FSI potential the following specific objectives have been outlined:

1. Develop a data base of sorbent SO_2 removal efficiencies using six sorbents with four coals at 2 Ca/S ratios in EPA's Innovative Furnace Reactor (IFR) at a high temperature (1200 °C) regime.
2. Obtain comparative SO_2 reactivity data for the six sorbents at mid-range temperatures (550 °C) in EPA's Graphite Furnace Reactor (GFR).
3. Characterize sorbent microstructure properties using x-ray diffraction (XRD) techniques in an effort to correlate these properties with sorbent SO_2 removal efficiencies.
4. Determine the potential for leaching of toxic metals from FSI ash using EPA's Extraction Procedure (EP) Toxicity Test.

SECTION 2

INTRODUCTION AND BACKGROUND

Emissions of sulfur oxides, principally SO_2, from combustion sources have drawn increased awareness and concern in recent years. In particular, SO_2 emissions from coal fired boilers used by utilities and industries have been implicated as major contributors to a growing acid precipitation problem. While long-term ecological effects of acid precipitation are a hotly debated subject, it is clear that a reduction in SO_2 emissions is greatly desirable. Factors to weigh in determining an SO_2 control technology are cost, SO_2 removal efficiency and ease of retrofitting to existing boilers. The optimum control technology would balance removal levels with the cost to the industry or utility (and ultimately the consumer). One technology that has received considerable attention is Furnace Sorbent Injection (FSI), which offers a relatively low capital cost, ease of retrofitting and reasonable removal efficiencies.

A large body of research on FSI is currently available. The effects of such fundamental parameters as injection temperature, sorbent type, particle size and SO_2 concentration have been investigated on the pilot scale. These investigations, along with on-going full-scale demonstrations, indicate that SO_2 removals of approximately 60 percent may be expected using commercially available calcium hydroxide [$Ca(OH)_2$] sorbents. Impacts of FSI on the boiler noted to date include increased slagging and fouling, increased mass loading on particulate removal systems, and alteration of the chemical composition of boiler ash.

The investigation at hand is designed to provide data at the pilot scale on SO_2 removal from a combustor fired with Illinois Basin coals and injected with a range of sorbent types. These comparative data, along with results from low temperature testing, physical analysis of the sorbents, and chemical analysis of the ash will be used to evaluate FSI as a control technology for facilities using Illinois Basin coals. Exceptionally high removal efficiencies could expand the range of applications for Illinois high sulfur coal at a lower cost than coal cleaning or wet FGD alternatives.

SECTION 3

EXPERIMENTAL PROCEDURES

In the following section, the experimental conditions used in satisfying the objectives outlined in Section 1 are given. Particular values for parameters are given where known. The four coals used in testing were identified as Illinois Basin Coal Sample Program (IBCSP) #1, #2, #6, and #9. Sorbents chosen for testing included three commercially available calcium hydroxides (Marblehead, Linwood and Snowflake), a dolomitic hydrate (Kemidol), a surfactant-modified calcium hydroxide (lignosulfonate modified Marblehead), and an alcohol hydrate provided by the Illinois State Geological Survey (ISGS). The ISGS sorbent was made by combining equal parts of each of the ten batches provided. This was necessary to insure that adequate sorbent was on hand for FSI testing in the IFR. Limited testing of the individual batches was done in the other reactor systems.

3.1 INNOVATIVE FURNACE REACTOR TESTS

Testing in the IFR consisted of determining baseline SO_2 concentrations in the flue gas while burning each of the coals at feed rates sufficient to yield a firing rate of approximately 47,000 Btu/h. Other secondary species monitored but not reported on included NO_x, CO, CO_2, and O_2. Table 3-1 lists the techniques used. Continuous emission monitors (CEMs) were calibrated using multiple calibration gases bracketing measured concentration levels. After determining a stable SO_2 concentration, sorbent was injected at a Ca/S ratio of approximately one and the SO_2 level monitored until an equilibrium level was achieved. Sorbent injection was then stopped and the SO_2 level allowed to return to baseline with time prior to repeating the test. SO_2 removal percentage was determined as the average of the duplicate tests. The entire procedure was then reinitiated with a Ca/S ratio of approximately two. The entire test matrix consisted of testing each coal with all six sorbents using duplicate runs (4 coals x 6 sorbents x 2 duplicate x 2 Ca/S ratios = 96 tests). Actual sorbent and coal feed rates were determined gravimetrically. After running on consecutive test days, slagging in the furnace required that it be run overnight with a gas lance in order to deslag the interior prior to reinitiating testing. A diagram of the IFR is shown in Figure 3-1.

3.2 GRAPHITE FURNACE REACTOR TESTS

Current supply to EPA's electrically heated GFR was regulated to yield a temperature profile with a peak of near 1,000 °F (535 °C) while declining rapidly with time (or distance) in the reactor. Flow rates sufficient to give a residence time of 0.75 s between 1,000 and 800 °C and an SO_2 concentration of 3,000 ppm were used. Each sorbent was injected under differential conditions and conversion to calcium sulfite (or sulfate) determined on solid samples collected by a cyclone separator. Figure 3-2 shows a cross-section of the GFR.

3.3 X-RAY DIFFRACTION TESTS

Each of the six sorbents were analyzed using XRD. Calcium hydroxide peak analysis was used to determine peak half widths. The Warren-Avenbach method of peak analysis was used to determine the following major properties:

TABLE 3-1

Instrument	Principal of Operation	Model Manufacturer	No.	Range
O_2	Paramagnetic	Beckman	875	0-5% 0-10% 0-25%
CO_2	Nondispersive infrared	Beckman	864	0-5% 0-15% 0-25%
CO	Nondispersive infrared	Beckman	865	0-5 ppm 0-1,500 ppm 0-2,500 ppm
NO_X	Chemiluminescent	TECO	10-AR	(Note a)
SO_X	UV-Vis	Anacon	400	0-1,000 ppm 0-4,000 ppm

Note a. 0-10 ppm
0-50 ppm
0-200 ppm
0-500 ppm
0-1,000 ppm
0-5,000 ppm
0-10,000 ppm

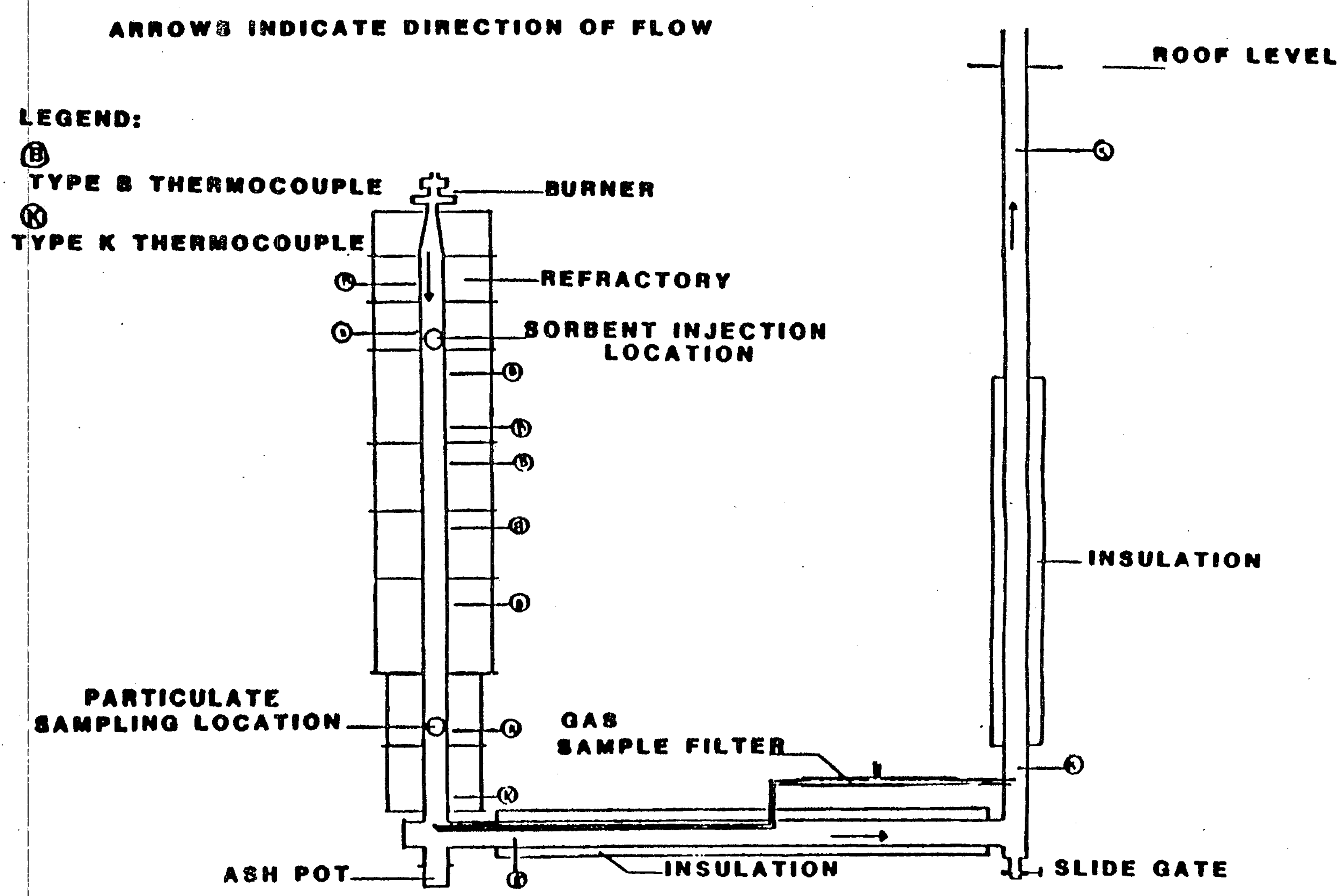

Figure 3-1. Innovative furnace reactor.

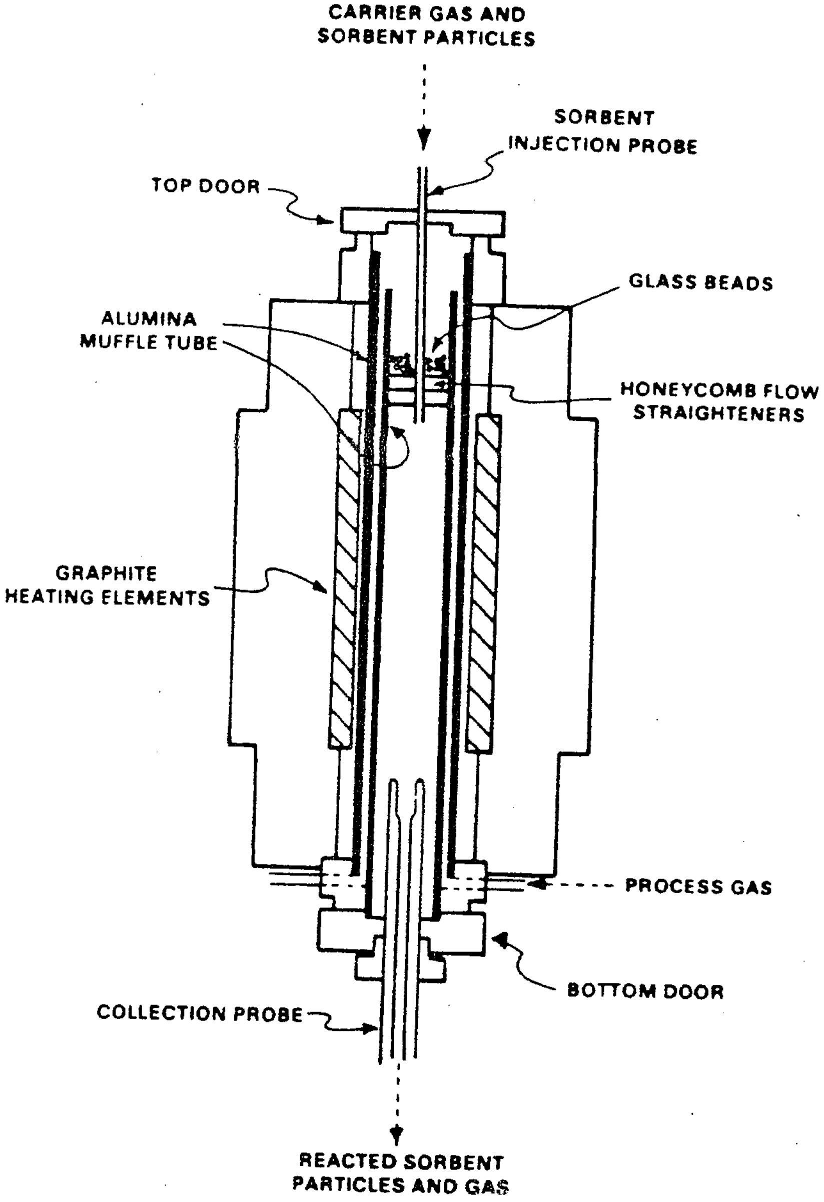

Figure 3-2. Cross section of the graphite furnace reactor.

1. Average crystallite size
2. Frequency of occurrence of column lengths as a function of column length, and the column length of maximum frequency of occurrence.
3. Half width of the frequency of occurrence column lengths as a function of column length.
4. Maximum determinable column length.
5. Strain at the average column length.
6. Strain as a function of column length.
7. Strain at the column length of maximum frequency of occurrence.
8. Strain at the maximum determinable column length.

3.4 EXTRACTION PROCEDURE TOXICITY TESTS

Toxicity tests were performed on ash taken from the baghouse during each of the baseline coal tests excluding coal #1 for which insufficient sample was collected. Analyses on eight RCRA regulated metals (antimony, barium, cadmium, chromium, lead, mercury, selenium, and silver) and pH were carried out using methods outlined in SW 846. The tests simulate leachate from a landfill or pond runoff. Ash from sorbent injection using one coal (IBCSP #6) and all six sorbents (Ca/S = 2) were also tested to determine the impact of FSI on disposal of ash. Previous work indicated that unreacted CaO acts to stabilize most of the metals, but an increase in leachate pH is expected.

3.5 STDR TESTING

Tests were run on the Short Time Differential Reactor (STDR) using 4 mg of sorbent exposed to process gas consisting of 3,000 ppm SO_2 in 5 percent O_2 and an N_2 balance preheated to 1,000 °F (538 °C). The reactor, shown in Figure 3-3, is designed to allow exposure times in the range of 0.3 to 5 s, while maintaining conditions differential with respect to SO_2 concentration.

3.6 ANALYTICAL PROCEDURES

Products from the GFR and STDR were analyzed for calcium and sulfate concentration by atomic absorption spectroscopy and ion chromatography, respectively. Samples were dissolved in DI water, 1N HCl and H_2O_2 and stirred for 5 min. The sample was then filtered into a volumetric flask and diluted for analyses.

Sorbent particle size analyses were performed on a Micromeretics Sedigraph 5100. Approximately 0.5 g of sample was dispersed in Micromeretics dispersant A11 and allowed to stir for 15 min. Particle size distributions were determined over the range of 50 to 1 microns in diameter.

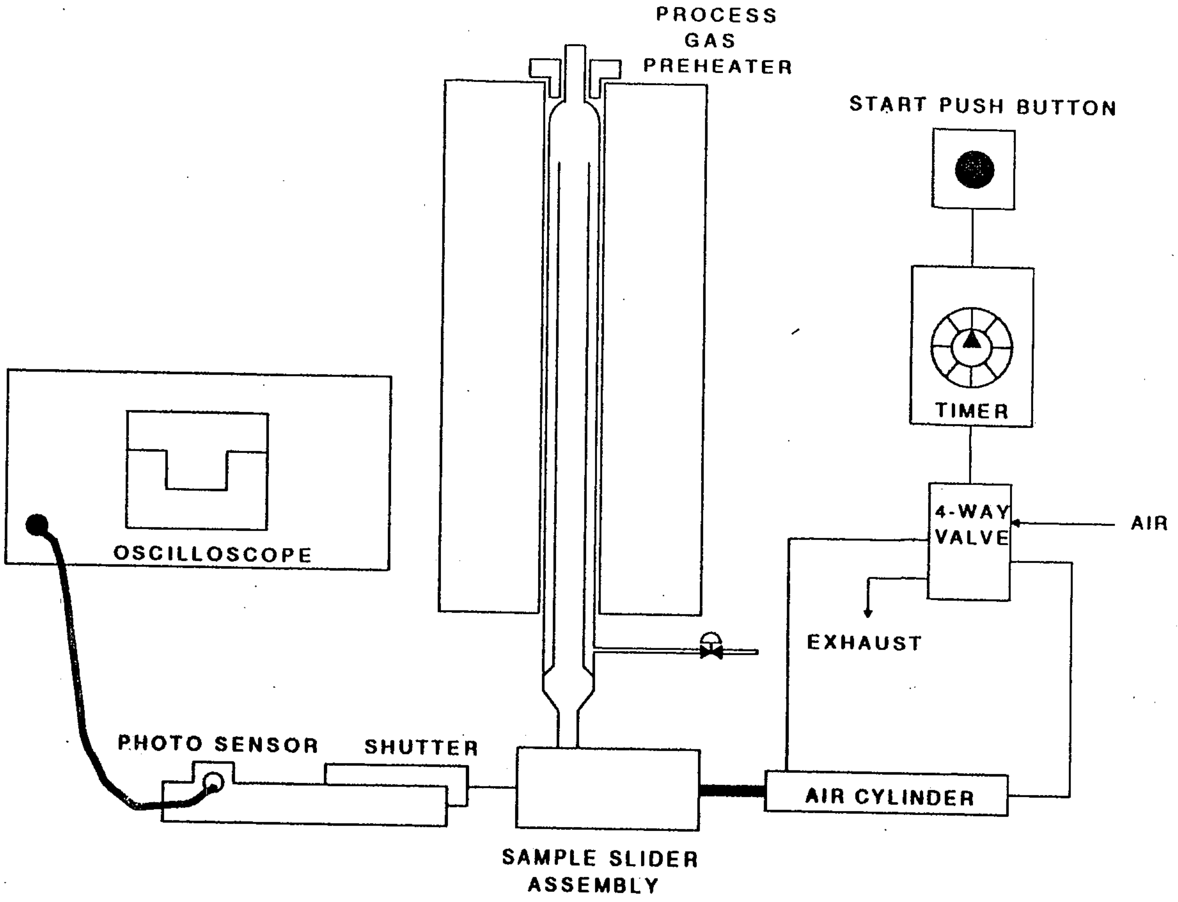

Figure 3-3. Diagram of STDR.

SECTION 4

RESULTS AND DISCUSSION

4.1 IFR TESTS

Prior to initiating testing in the IFR, baseline data was collected on the coals and sorbents. Information on the coals, compiled in Table 4-1 was provided by the ISGS. Table 4-2 presents data on the sorbent's physical and chemical characteristics provided by the ISGS and our analyses. Calcium values determined in-house were used in calculating Ca/S ratios in IFR testing.

Results for FSI testing on the IFR are compiled in Figure 4-1. The data presented are estimated SO_2 removal percentages at Ca/S of 2, calculated by extrapolating linearly from the mean removals at both the Ca/S ratios run for each coal/sorbent combination. Some repeats were necessary due to difficulties encountered in controlling the sorbent feed rate in early tests. The compiled raw data are given in the appendix.

Upon observing Figure 4-1, several trends in the data can be noted. SO_2 capture levels for the IBCSP 2 coal are substantially lower for all sorbents tested (with the possible exception of the Marblehead hydrate) than is the case for the other coals. It is interesting to note that while the sulfur content of the IBCSP 2 coal (3.23 percent) is bracketed by the other coals, it differs from them in one important aspect. Unlike the other coals tested, pyritic sulfur accounts for the majority of the sulfur present in IBCSP 2, giving a pyritic/organic sulfur ratio of 2.53 compared to values less than 1 for the other coals. No explanation for the apparent adverse effect of a high pyritic/organic sulfur ratio on FSI is currently available. The need for future work to verify and to determine the cause of this phenomenon is suggested.

Furthermore, when the data from the three other coals (IBCSP 1, 6 and 9) are viewed collectively, the SO_2 removals by individual sorbents do not differ radically from coal to coal. In each case the relative standard deviation of the mean SO_2 removal percentage (standard deviation of mean removal divided by the mean) is less than 10 percent. This could be an indication that the pyritic/organic sulfur ratio of each coal is the largest coal specific factor in variations in FSI performance using the same sorbent.

The commercially available calcium hydroxide sorbents; Linwood, Marblehead and Snowflake, all yield approximately the same values for SO_2 removal percentages when excluding the data from IBCSP 2. The sorbents hydrated under special conditions however (the lignosulfonate modified Marblehead and the ISGS alcohol hydrate), clearly exhibit superior performance. Tests in EPA/AEERL's in-house laboratories attribute the enhanced performance of the modified Marblehead to its ability to resist sintering at the high temperatures seen in FSI. The performance of the ISGS sorbent may be related to its very small particle size. Recent in-house tests have demonstrated the importance of sorbent particle size to sulfur capture. Mixing studies have shown that in many instances, sorbent injection takes place under conditions likely to result in limitations on mass transfer rates of SO_2 to the reacting particle. In such a regime, ultimate sorbent reactivity will be inversely related to the size of the reacting particle. More work on such

TABLE 4-1. COAL CHARACTERISTICS

	IBCSP 1	IBCSP 2	IBCSP 6	IBCSP 9
Moisture	14.14	13.62	10.42	6.60
Volatile Matter	44.12	43.34	39.56	35.90
Fixed Carbon	45.62	49.92	51.44	56.10
Ash	10.28	6.66	9.00	8.00
Carbon	67.66	73.31	71.64	74.72
Hydrogen	4.86	5.21	4.73	5.06
Nitrogen	1.18	1.47	1.78	1.77
Oxygen	11.63	10.09	9.05	9.32
Pyritic Sulfur	1.20	2.34	1.83	—
Organic Sulfur	3.00	0.92	1.94	—
Pyritic/Organics Ratio (no units)	0.40	2.53	0.92	—
Total Sulfur	4.26	3.23	3.77	1.17
Calorific Value (Btu/lb)	12,606	13,526	13,248	13,295

All values in wt % except where noted.

TABLE 4-2. SORBENT CHARACTERISTICS

Sorbent	Ca (wt %)	Mean Particle Diameter (μm)
Kemidol	34.3	3.93
Linwood	49.9	2.88
Marblehead	50.1	4.33
Modified Marblehead	50.0	3.47
Snowflake	47.5	3.46
ISGS Mix	47.4	2.06
ISGS BH-16	—	1.90
ISGS BH-20	—	2.67
ISGS BH-22	—	2.24
ISGS BH-24	—	2.01
ISGS BH-29	—	1.68
ISGS BH-30	—	2.09
ISGS BH-31	—	2.01
ISGS BH-32	—	2.35
ISGS BH-33	—	2.08
ISGS BH-34	—	2.41

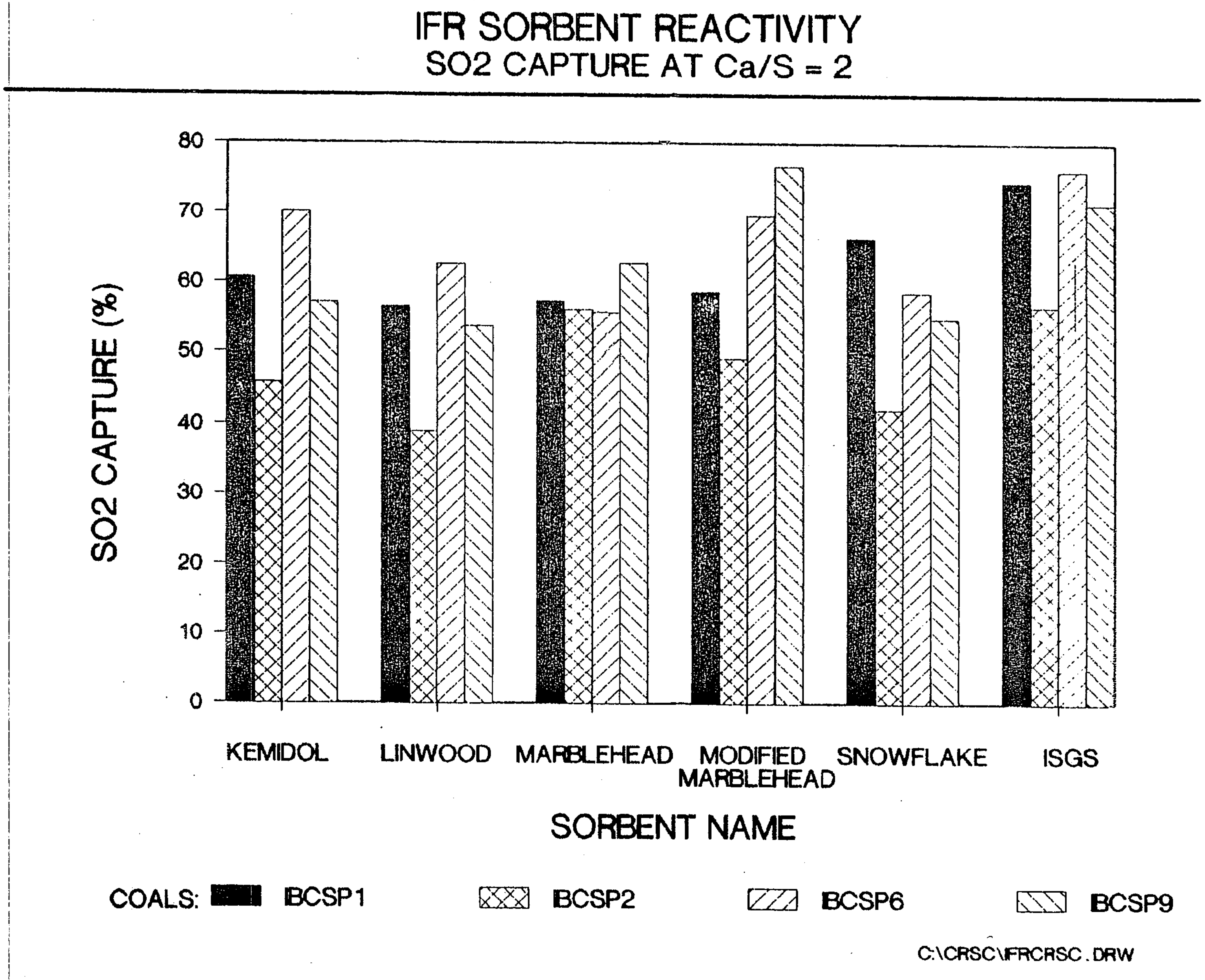
IFR SORBENT REACTIVITY
SO2 CAPTURE AT Ca/S = 2
SO2 CAPTURE (%)
0
10
20
30
40
50
60
70
80
KEMIDOL
LINWOOD
MARBLEHEAD
MODIFIED MARBLEHEAD
SNOWFLAKE
ISGS
SORBENT NAME
COALS:
BCSP1
BCSP2
BCSP6
BCSP9
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Figure 4-1.

mixing phenomena is needed to find ways of injecting sorbent in such a manner as to maximize reaction.

It is interesting to note that for these tests the dolomitic hydrate, Kemidol, did not outperform the purely calcium based sorbents. Past tests noted in the literature indicate that Kemidol would be expected to yield higher SO_2 removal percentages than the calcitic hydroxides at the same Ca/S ratios. In the tests shown in this work, removal percentages for the dolomitic hydroxide were comparable to those seen for the calcitic hydroxides and were not high enough to offset the increased solids loading on particulate removal systems that necessarily accompanies FSI with dolomitic sorbents due to the unreactive magnesium oxide portion.

The overall impression of the applicability of FSI as a SO_2 control technology for Illinois coals is a positive one. With the exception of IBCSP 2, which gave lower results for unknown reasons discussed earlier, SO_2 removals for each of the coal/sorbent tests approached or exceeded 60 percent at a Ca/S ratio of 2. Indeed, tests with the specially modified sorbents routinely exceeded 70 percent. These test results strongly recommend FSI as a cost effective means of controlling SO_2 emissions from coal-fired combustors.

4.2 ECONOMIZER INJECTION TESTING

Results from economizer temperature sorbent injection testing on the GFR are shown in Table 4-3. The data show a clear inverse relationship to sorbent particle size as measured using the sedigraph; as particle size decreases, the conversion of the sorbent to the calcium sulfite product in the GFR increases. Again, this is indicative of mass transfer resistances acting to control the rate of reaction, rather than other potentially faster mechanisms such as inherent chemical kinetics. Removing these resistances may show a faster true rate of reaction.

TABLE 4-3. RESULTS FROM ECONOMIZER INJECTION TESTS ON GFR

Sorbent	Mean Conversion (%)
Marblehead	9.8 ± 0.7
Modified Marblehead	11.0 ± 1.1
Snowflake	11.7 ± 1.0
Linwood	15.2 ± 2.9
ISGS BH-20	17.7 ± 1.0
ISGS BH-24	17.6 ± 1.1
ISGS BH-29	19.9 ± 2.2
Kemidol	15.3 ± 2.5

Data obtained from minimum of 10 runs at 1,000 °F, $t_R = 0.75$ s, 3,000 ppm SO_2, 5 percent O_2, N_2 balance.

The Short Time Differential Reactor (STDR) is designed to operate under differential conditions with respect to SO_2 concentration. Using small particles, such as in this work, along with a high process gas throughput (resulting in a high gas velocity with respect to the sorbent particles), serves to remove film layer and pore diffusion mass transfer resistances as potential rate limiting steps for the sorbent/SO_2 reaction. Results from testing in the STDR with an SO_2 concentration of 3,000 ppm using ISGS BH-29 sorbent are shown in Figure 4-2. Similar conversions were obtained with Linwood hydrated lime over the same time range. These results predict an SO2 removal of roughly 55 percent for a 1 s residence time and Ca/S ratio of 2 when injecting sorbent at or near 1,000 °F. This removal percentage is slightly lower than those reported in previous works. More work is needed to accurately quantify the fundamental rate of the sorbent/SO_2 reaction under economizer injection conditions using reactors like the STDR prior to predicting potential SO_2 removal levels. The effects of parameters such as SO_2 concentration, sorbent surface area and sorbent porosity on reaction rate must be thoroughly investigated.

4.3 X-RAY DIFFRACTION ANALYSES

It has been proposed that crystallite size can affect the gas-solid reactions by modifying the interface between the two phases. It is further proposed that crystal lattice strain could contribute to reactivity by decreasing the stability of the solid and producing a source of activation energy from the strain energy stored in the lattice. Some of the crystallite size and strain data for the samples analyzed, along with the XRD peak half widths, are shown in Table 4-4.

This table gives the percent conversion data from the sorbents tested in the IFR. The percent conversion data is reported in units of moles of Ca reacted divided by moles of Ca available times 100.

It was seen that the reactivities for coals 1, 6 and 9 were quite similar. The analysis of variance showed a significance level of 0.9 for the sorbents and 0.06 for the coals. Consequently, it was considered reasonable to average the coal reactivities to increase the reliability of the sorbent characterization. To test the hypothesis that the individual x-ray line broadening (XLB) factors were related to reactivities, regression functions were derived using the observed experimental reactivities for coals 1, 6 and 9.

From regression data it was found that the best single estimator of reactivity was maximum column length.

In the next phase, regression equations were derived for relating the XLB factors two at a time to the observed reactivities. For the 15 pairs of factors, the correlation coefficients varied from 0.13 to 0.79. The two best pairs of estimators were average column length and modal column length with correlation coefficients of 0.78 and 0.79, respectively. These values were considered quite significant, considering their derivation was subject to coal and furnace variability.

Since the increase in correlation was vastly improved by using two factors, it was natural to go on to three factors for the analysis. For triplets, the correlation coefficient varied from 0.40 to 0.99. It would appear that it is possible to almost completely characterize the microstructural contribution to reactivity with three XLB factors. The best correlation coefficient of 0.99 came with considering the average column length, modal column length, and strain at maximum column length.

Results and predictions obtained from the XLB regression data on the sorbents evaluated can be seen in Figure 4-3. The three XLB factors mentioned above appear to be the best estimators of reactivity from the number of samples analyzed to date. The linear correlation coefficient of 0.99 for the relation is conclusive and is considered reliable for ranking sorbent materials. Future studies of other sorbents could further establish the reliability of this method.

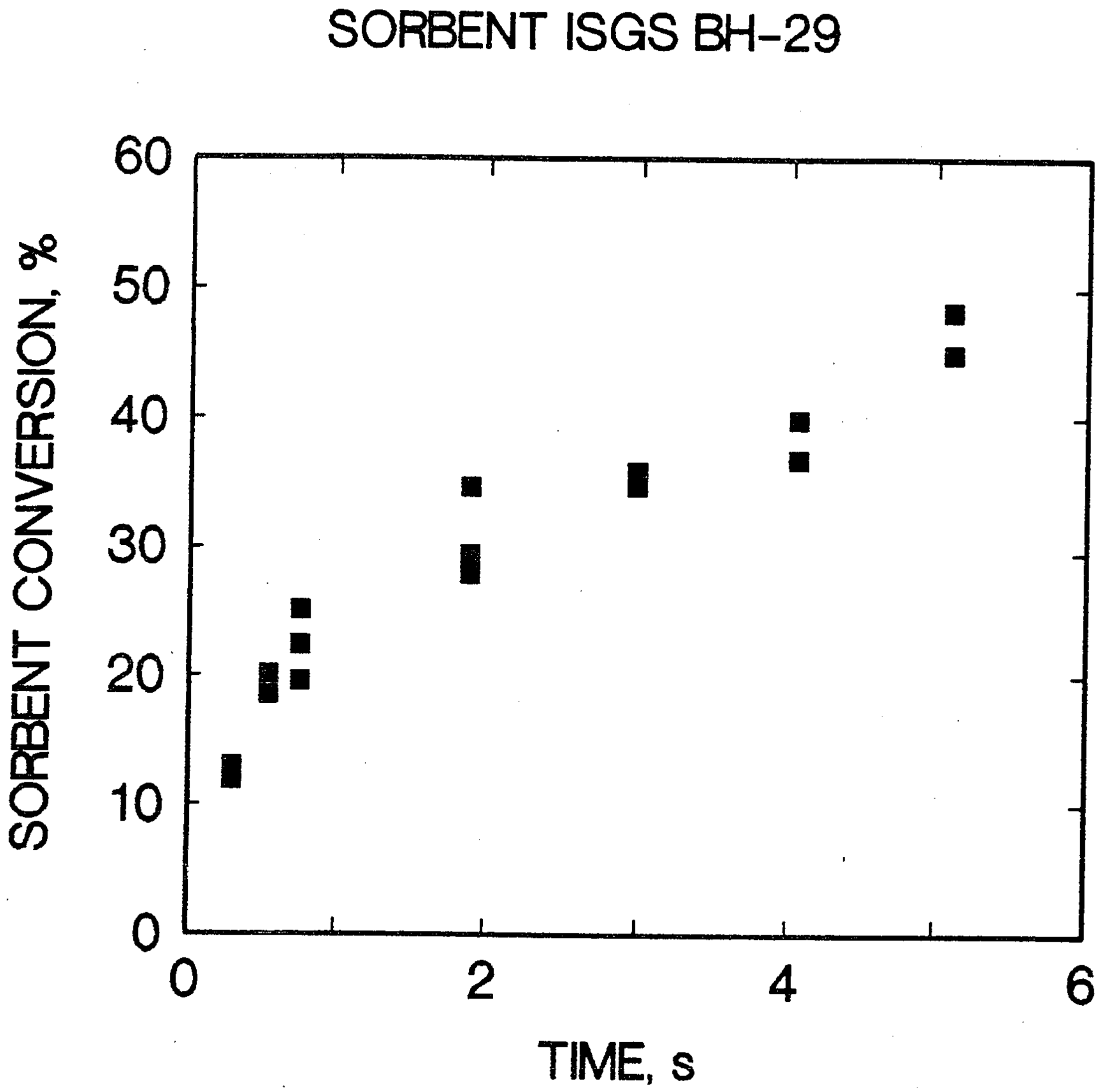

Figure 4-2.

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Table 4-4. ILLINOIS COAL REACTIVITY AND XRD PEAK SHAPE DATA

	Kemidol	Linwood	Marblehead	Marblehead	Modified Snowflake	ISGS
Reactivity IBCSP 1	58.7	57.9	57.6	59.8	66.6	76.6
Reactivity IBCSP 2	42.6	38.1	57.3	49.5	47.7	58.8
Reactivity IBCSP 6	67.8	60.1	53.8	67.	57.6	74.2
Reactivity IBCSP 9	52.7	52.3	63.6	75.5	57	69.4
Reactivity Avg 1, 6, 9	59.733	56.766	58.333	67.433	60.4	73.4
Avg Col Lnth	9.8	11.5	9.9	8.7	15	11.5
Max Col Lnth	45	38	41	32	50	33
Max Freq Col Lnth	3.37	5.33	3.57	3.93	7.47	6.53
Strain (Avg Col Lnth)	2.18 E-3	2.2 E-3	2.2 E-3	2.34 E-3	1.71 E-3	2.22 E-3
Strain (Max Col Lnth)	1.16 E-3	1.34 E-3	1.25 E-3	1.49 E-3	9.1 E-4	1.38 E-3
Strain (Max Frq Col Lnth)	3.27 E-3	2.99 E-3	3.26 E-3	2.84 E-3	2.55 E-3	2.86 E-3
Fwhm Order I	0.37	0.467	0.415	0.529	0.397	0.536
FWHM Order II	0.604	0.719	0.647	0.808	0.583	0.803

Reactivities in units of SO_2 removal percentage at Ca/S = 2

Lengths in units of manometers

4.4 ASH ANALYSES

Results from the EP Toxicity tests are given in Table 4-5. As anticipated, values for all of the regulated metals are below the RCRA limits. Sorbent injection would appear to stabilize many of the metal species, particularly arsenic and cadmium. While the final pH values are below RCRA limits, they are high enough to elicit some concern. Methods for stabilizing the ash or neutralizing leachate form the ash may bear investigation.

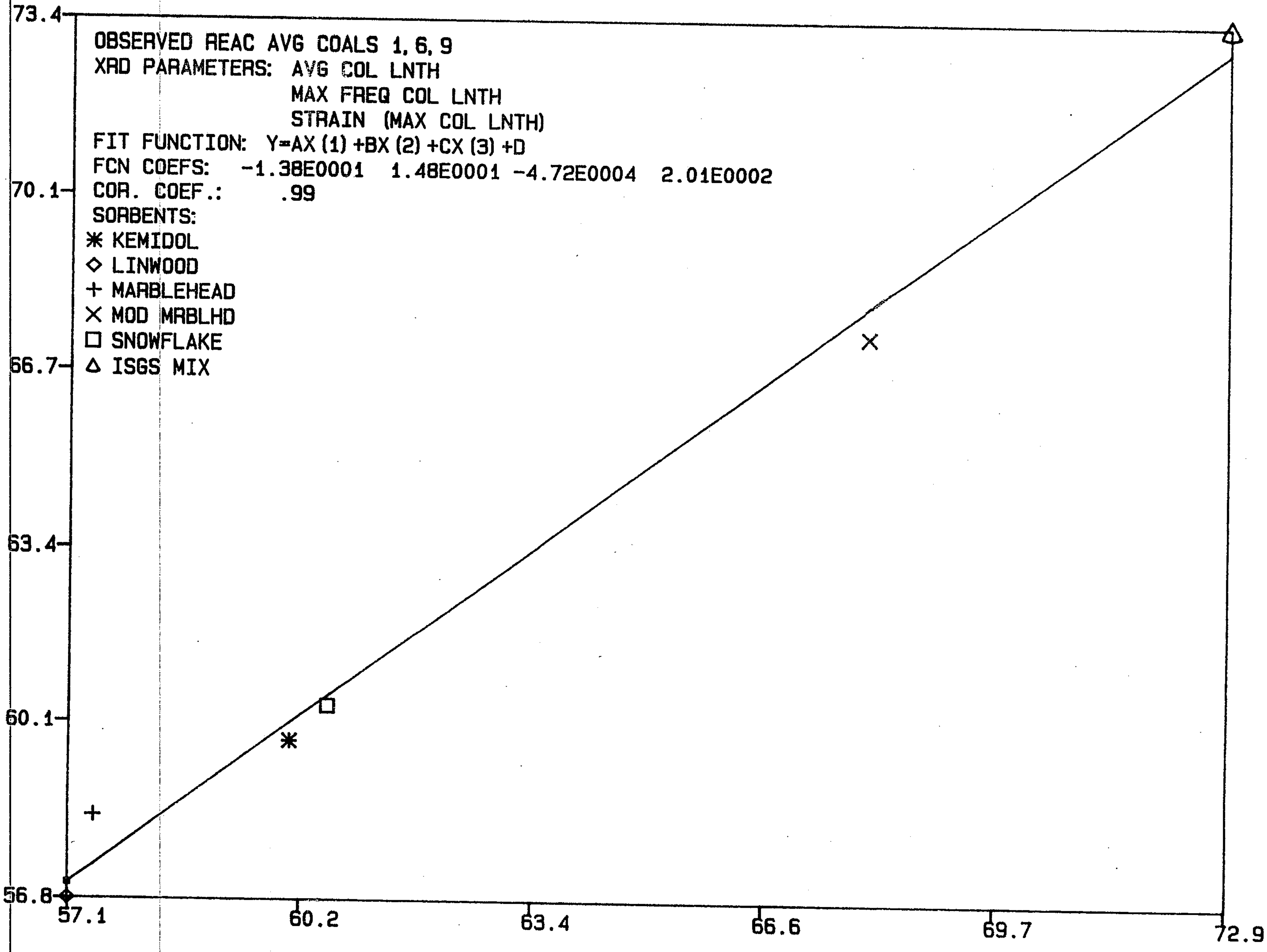

Figure 4-3. Reactivity Predicted by XLBN vs that Observed in IFR.

TABLE 4-5. RESULTS OF EP TOXICITY TESTS ON FSI ASH

Parameter	RCRA Inlet EPA Method	Coal #2 (mg/L)	Coal #6 (mg/L)	Coal #9 (mg/L)	Kemidol (mg/L)	Linwood (mg/L)	Marblehead (mg/L)	Modified Marblehead (mg/L)	Snowflake (mg/L)	ISGS (mg/L)	Spike (mg/L)	(% Recovery)
Arsenic	206.2	5	0.049	0.034	0.069	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	109
Barium	200.7	100	0.26	0.21	0.26	0.29	0.15	0.12	0.12	0.12	0.093	87
Cadmium	200.7	1	0.11	0.088	0.082	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	97
Chromium	200.7	5	0.043	0.19	0.36	0.044	0.063	0.072	0.054	0.075	0.071	89
Lead	239.1	5	0.23	0.025	0.13	0.14	0.029	<0.001	<0.001	0.035	<0.001	104
Mercury	245.1	0.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	95
Selenium	270.2	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	71
Silver	200.7	5	0.032	<0.01	0.022	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	45
Final pH		12.5	5.1	5.0	4.9	12.4	11.9	12.2	11.8	11.9	11.8	NS

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Pilot scale testing of the SO_2 removal potential of FSI with Illinois Basin coals showed that removal percentages in excess of 60 percent can be readily achieved using commercially available sorbents and a Ca/S ratio of 2. The specially prepared sorbents gave removals in excess of 70 percent. Lower captures were noted for coal high in pyritic sulfur (as opposed to organic sulfur) however. Further investigation is necessary to verify this phenomenon and to find an explanation. The greatest removals were seen using the ISGS alcohol hydrate. It is believed that its performance is enhanced by its small particle size and the resultant mixing benefits gained by such size. More investigation of both bench and pilot scale mixing phenomena is indicated to understand how these parameters affect sorbent reactivity. Better injection techniques could minimize particle size effects through greater mixing, yielding increased removals for larger particles.

Testing of sorbent injection at economizer temperatures showed that removals of roughly 55 percent at a Ca/S ratio of 2 can be expected, however not much is known currently about fundamental reaction kinetics for the mid-temperature sorbent/SO_2 reaction. In order to more accurately predict the full scale performance of injection of sorbent in this temperature region, more work is needed to clarify the effects of temperature, SO_2 concentration and sorbent characteristics on reactivity.

X-Ray Diffraction tests indicated that the sorbent microstructural characteristics of average column length, modal column length and strain at maximum column length can provide a basis for prediction of sorbent performance in FSI applications. Verification of the predictive power of these parameters is warranted. Testing with additional sorbents under the same conditions as well as additional testing of the same sorbents at another facility is called for.

Analyses of the injection ash showed that it could be considered nonhazardous in terms of leaching of heavy metals. The pH of the leachate is a concern however, because of its alkaline nature. Further investigation into methods of disposal or utilization of FSI waste is necessary.

APPENDIX

FSI DATA

Coal	Sorbent	Baseline SO_2 (ppm)	Injected SO_2 (ppm)	Removal	Ca/S
IBSCP 1	Kemidol	3167	1866	41.1	1.12
	Kemidol	3167	1066	66.3	2.25
	Linwood	3468	2403	30.7	0.87
	Linwood	3468	1703	50.9	1.75
	Marblehead	3180	2302	27.6	0.91
	Marblehead	3180	1504	52.7	1.83
	Mod. Marblehead	3394	2186	35.6	0.93
	Mod. Marblehead	3394	1508	55.6	1.86
	Snowflake	3161	2249	28.8	0.85
	Snowflake	3161	1371	56.6	1.70
	ISGS	3120	1979	36.6	0.79
	ISGS	3120	1204	61.4	1.58
IBSCP 2	Kemidol	2340	1632	30.2	1.12
	Kemidol	2340	1170	50.0	2.24
	Linwood	2469	1852	25.0	0.94
	Linwood	2469	1536	37.8	1.91
	Marblehead	2433	1560	35.9	0.92
	Marblehead	2433	1139	53.2	1.85
	Mod. Marblehead	2332	1765	24.3	0.91
	Mod. Marblehead	2332	1271	45.1	1.82
	Snowflake	2541	1890	25.6	0.88
	Snowflake	2541	1472	42.1	1.75
	ISGS	2288	1538	32.8	0.85
	ISGS	2288	1136	50.3	1.70
IBSCP 6	Kemidol	2817	1488	47.2	1.12
	Kemidol	2817	659	76.6	2.25
	Linwood	2746	1546	43.7	1315
	Linwood	2746	842	69.3	2.30
	Marblehead	2722	1517	44.3	1.03
	Marblehead	2722	1187	56.4	2.07
	Mod. Marblehead	2788	1436	48.5	1.11
	Mod. Marblehead	2788	702	74.8	2.22
	Snowflake	2918	1852	36.5	1.10
	Snowflake	2918	1058	63.7	2.21
	ISGS	2862	1151	59.8	1.07
	ISGS	2862	610	78.7	2.14
IBSCP 9	Kemidol	882	498	43.5	1.33
	Kemidol	882	260	70.5	2.66
	Linwood	1075	766	28.7	1.06
	Linwood	1075	464	56.8	2.12
	Marblehead	908	624	31.2	0.87
	Marblehead	908	404	55.5	1.74
	Mod. Marblehead	869	533	38.7	1.08
	Mod. Marblehead	869	144	83.4	2.16
	Snowflake	1032	611	40.8	0.92
	Snowflake	1032	488	52.7	1.84
	ISGS	960	508	47.1	1.16
	ISGS	960	186	80.6	2.32