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PETC INTERIM REPORT: December 1995
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INTRODUCTION

The Moving-Bed Copper Oxide Process is of particular interest since it is capable of simultaneously removing SO_2 and NO_x from flue gas; it can meet the goals of the Superclean Emissions Control subprogram of the Flue Gas Cleanup Program; and it can beneficially be integrated into the design of advanced power systems, such as HIPPS. This process has been the subject of a small scale experimental test program with Rockwell and is currently being evaluated in a life-cycle test system (LCTS) with a moving-bed flue gas contactor at DOE's Pittsburgh Energy Technology Center (PETC). An experimental data base will be established that will be used to verify reported technical and economic advantages, to optimize process conditions, to provide scale-up information, and to validate absorber and regenerator mathematical models.

The chemistry of the process is relatively straightforward. In the absorption step, SO_2 in the flue gas reacts with copper oxide, supported on small spheres of alumina, to form the sulfate. Ammonia is injected into the flue gas before the absorption reactor and an SCR-type reaction occurs that reduces the nitric oxides in the flue gas. In the regeneration step, the copper sulfate is reduced in a regenerator via a reducing agent, such as natural gas, and a concentrated stream of SO_2 is produced. Another advantage of the process is the lower pressure drop across the moving-bed configuration reduces power consumption and thus influences the overall economic costs. The moving-bed process also has a lower projected sorbent attrition rate compared with other reactor configurations. Lastly, high sorbent utilization (the degree to which the sorbent absorbs its theoretical maximum level of SO_2 based on the metal oxide loading on the alumina sphere) can be realized in a moving-bed design.

In this communication, the results from five tests (MBCUO-2 through MBCUO-6) with the LCTS are discussed. During MBCUO-2 and MBCUO-3, the effect of absorber parameters on sorbent performance (e.g., SO_2 removal) and operational performance was investigated. UOP sorbent was used in this work. During MBCUO-4, natural gas regeneration was evaluated with the UOP sorbent. In MBCUO-5, a Grace sorbent with a slightly higher copper loading (7.0% versus the UOP 6.4%) was used to further evaluate natural gas regeneration and initially investigate hydrogen regeneration. Finally, the Grace sorbent was used again and hydrogen regeneration was investigated in MBCUO-6. Initial shakedown results leading to these parametric studies were previously described in a topical report (Pennline et al., 1995) and in a letter of Pennline to Darguzas dated June 19, 1995. Flow visualization tests after the initial coal combustion characterization tests in April 1995 can also be found in the letter of Pennline to Darguzas dated June 19, 1995.

EXPERIMENTAL

The process has been investigated using the LCTS that has been designed, constructed, and operated at PETC. The LCTS has the capability of operating in a continuous integrated mode, specifically related to the absorption and regeneration steps. Flue gas can be generated by a combustor that burns approximately 40 lbs/hr of pulverized coal, resulting in a nominal flue gas flow rate of 110 scfm. Coal is pulverized in an adjacent building, stored in a 20-ton hopper, periodically transported to the LCTS feed silo, and then fed from the silo by a feed screw into a stream of transport air for combustion in the furnace. The combustor can also be fired using natural gas for purposes of total flue gas production, of support for coal combustion, and of preheating the absorber and associated vessels thus preventing condensation of corrosive flue gas components, such as sulfuric acid, during initial coal burning. The flue gas exiting the combustor passes through heat exchangers so that a prescribed inlet absorber temperature can be maintained. The flue gas can be spiked with SO_2 and NO supplied from cylinders to adjust these concentrations to those of the desired test levels. Typically, NO is spiked for a 1-3 hour period after steady-state is reached at a set of parameters. Consequently, ammonia is injected into the flue gas upstream of the absorber to facilitate the catalytic reduction of nitrogen oxides to nitrogen and water vapor in the absorber. A controlled flue gas bypass provides a slip stream around the absorber, enabling the desired flow of flue gas through the absorber to be maintained. After passing either through or around the absorber, the flue gas is cooled by humidification and then passed through a baghouse for removal of any residual fly ash.

The sorbent process stream in the LCTS involves a closed-loop cycle of sorbent transported through four major vessels. The sorbent absorbs flue gas contaminants in the moving-bed absorber, passes through a fluidized-bed sorbent heater where the sorbent is heated with air and the products of a natural gas combustor, enters a regenerator where sulfur-containing species are released after treatment of the sorbent with a reducing gas, and lastly passes through a fluidized-bed air cooler prior to returning to the absorber. The sorbent is gravity fed through all four vessels, with the exception being the line connecting the absorber exit with the fluidized-bed sorbent heater. In this line, a pneumatic transport system sends the sorbent to an elevated location (i.e., the sorbent heater) to repeat the gravity-fed sorbent cycle. The hot air from the sorbent heater is vented through a baghouse for dust removal, and the regenerator offgas is vented through an incinerator.

The entire system operates at pressures close to ambient; the various vessel pressures are maintained by forced draft and induced draft blowers and control valves. The absorber and regenerator have externally mounted heaters for temperature maintenance, and typically operate at 750 and 850°F, respectively. Gas analyzers and various instrumentation have been used in the experimental characterization of the process.

Steady-state at a set of process parameters was typically defined by following key parameters and calculated quantities (e.g., SO_2 removal, certain thermocouple readings from the absorber and regenerator, regenerator off-gas composition, etc.). Once at the steady-state condition, operation of the LCTS continued for an additional period of time. Data was then averaged over this period of time or a smaller representative era within the period. The parameters and calculated quantities in the detailed and summary tables represent the average of this data or calculation over the designated steady-state period. Absorber removal efficiencies are corrected for air in-leakage. Also, inlet and outlet analyzer readings for the absorber are adjusted to reflect a constant inlet oxygen concentration of 3.6%. (Calculated quantities are defined in the Appendix of the topical report of Pennline et al. (1995).) These tables will be further refined by examining test logbooks to assure that there are no additional changes that may need to be recognized. It is felt that minor changes with little significant impact on the results will occur. Tables 1-5 are summaries of the results from the respective tests MBCUO-2 through MBCUO-6. The more detailed parameters are found in Tables 6-10, that correspond to tests MBCUO-2 through MBCUO-6.

Several items are noteworthy.
(1) The period designation in the summary tables reflects that found in the test plan for a particular test, but the detailed tables list the periods in numerical order. In either case, the periods are listed in chronological order and a one-to-one correspondence exists between tables of the same tests.
(2) Certain periods were not used in some of the data discussion because it was determined that steady-state was not attained or that operational problems during the period significantly impacted the experimental results. An example of this was the first two periods of MBCUO-3, where the Perma Pure filters malfunctioned and thus gave erroneous information.
(3) During testing, a summary sheet is updated daily. (See Table 11 for a first hand look at the results of MBCUO-7.) These sheets aid in directing and planning the course of the testing during operation. A steady-state is determined; data results "eyeballed"; and information hand recorded. The detailed and summary tables represent information that was computer-averaged over the steady state period.
(4) Within a particular study of a parameter, a systematic change of only that parameter was conducted and a comparison with subsequent test periods was performed.

DISCUSSION AND RESULTS

Absorber Parametric Testing: Tests MBCUO-2 and MBCUO-3

Sorbent performance and operational performance of the LCTS are presented in the attached tables for various parametric conditions. The UOP sorbent used was 1/16-inch diameter spheres of alumina containing a 6.4 weight percent copper loading.

During earlier shakedown studies, several issues were resolved so that a baseline test could be defined. One concern was that the regeneration step with natural gas was not entirely effective. A batch test in the regenerator identified the regeneration conditions that would be used throughout Tests MBCUO-2 and MBCUO-3. A temperature of 850°F and a 3-hr sorbent residence time with an excess of natural gas (typically twice the stoichiometric requirement) was sufficient to regenerate the sorbent.

The moving-bed absorber mathematical model of Young and Yeh (1993) was used as a means to define a baseline test so that changes in parameters could be quantified in the parametric study. The shakedown tests also indicated that sorbent flow in the original reactor design was not ideal, and cold flow studies dictated that the reactor width be 1 ft. (See letter of Pennline to Darguzas dated June 19, 1995.) Final absorption conditions for the baseline are a cross-sectional area of 8-ft^2, bed thickness of 5 inches, temperature at 750°F, sorbent flow of 1-lb/min, and a flue gas flow of 110-scfm produced by burning natural gas and spiking to a level of 2250 ppm of SO_2. Regeneration conditions described above were employed. Periodically during the parametric testing, the baseline condition was repeated to assure that the activity of the sorbent, as well as the operational response of the LCTS, was maintained.

The effects of absorption temperature, inlet SO_2 concentration, sorbent flow, and flue gas flow on the pollutant removal efficiencies in the absorber were systematically investigated. Absorber model predictions were also compared to the actual SO_2 removals at a set of conditions. The SO_2 removal of the baseline test was typically 93 percent.

Temperature

In the temperature study, four temperatures of absorption were investigated: 591, 705, 749, and 801°F, corresponding to the test periods MBCUO-3-8, MBCUO-3-2A, MBCUO-3-1A, and MBCUO-3-3, respectively. From past investigations, the optimum temperature of absorption is 750°F. Results of the LCTS testing (see Figure 1) would indicate that temperature fluctuation between 700 to 800 °F due to upsets in a commercial process would not have an appreciable impact on SO_2 removal. However, the lower the temperature the less activity as depicted by the 76.6 percent removal at the 591°F temperature level.

Flue Gas Flow Rate

Increasing the flue gas flow rate through the bed results in a decrease in the SO_2 removal. An explanation for this is that, when the gas flow is increased, the effective Cu/S feed ratio into the bed is decreased, and also the gas residence time within the bed is decreased. This effect can be seen in the data when the flue gas flow rate was doubled from near 55 (MBCUO-2-2A) to near 110 scfm (MBCUO-3-1A) and the other absorber parameters were held constant. From these initial tests, the nominal 110 scfm condition was chosen as the baseline since an observable change from the SO_2 removal at the lower flue gas flow rate could be difficult during the other parametric scans.

Inlet SO_2 Concentration

The impact of the inlet flue gas SO_2 concentration was also investigated. Essentially, as the SO_2 concentration increases, the effective Cu/S feed ratio decreases, thus causing a decrease in removal efficiency. Results can be seen in Figure 2 when the concentration levels of SO_2 were 1500, 2242, 3059, and 3244 ppm, simulating the concentrations in flue gas when a mid- to high-sulfur coal is combusted. The respective SO_2 percent removals for periods MBCUO-3-4, MBCUO-3-1A, MBCUO-2-3, and MBCUO-3-5 were 96.3, 93.2, 85.9, and 81.2, respectively.

Sorbent Flow

The effect of changing the sorbent flow on the SO_2 removal efficiency was also investigated. During this set of parametric tests, sorbent samples were withdrawn from the regenerator to verify that the regeneration step was complete. Thus the sorbent flowing into the absorber should have the same available copper for each sorbent flow variance. Effects of varying the sorbent flow can be seen at two gas flow conditions. The first is at a 55 scfm gas flow where sorbent flow was increased from 0.5 to 1.0 lb/min. A corresponding increase in SO_2 removal (94.0 to 95.2 percent) occurred as seen in MBCUO-2-1 and MBCUO-2-2A. At 110 scfm, the sorbent flow rates for three sets of conditions for periods MBCUO-3-6, MBCUO-3-1A, and MBCUO-3-7 were 0.75, 1.0, and 1.25 lb/min respectively, with corresponding SO_2 removals of 86.5, 93.2, and 91.1 percent. Except for the latter point as seen in Figure 3, the trend is the same indicating that a higher sorbent flow of regenerated sorbent will enhance the SO_2 removal efficiency of the absorber. However, in a commercial installation, an optimum sorbent flow should be attained to minimize the cost of sorbent transport and the effects of sorbent attrition.

NO_x Removals

As mentioned previously, NO was injected after certain test period conditions attained steady-state. Once the chemilumenescent analyzers established the NO spike concentration, ammonia was injected to a flow that established a 90 or 95% NO_x removal by again following the chemilumenescent analyzers. The molar flow of ammonia was determined by the flow settings, and a molar ratio of ammonia to nitric oxides was then calculated. From Table 2, the ratio in MBCUO-3 was between 0.85 and 1.05, with most conditions below 1.0. A similar NH_3/NO ratio had been found in earlier copper oxide work, indicating that a molar ratio less than one can reduce a vast majority of the NO_x. A wet chemical sampling technique that bubbled the flue gas through a hydrochloric acid solution was used to determine if ammonia slippage occurred. The solution is further analyzed by using an ion electrode technique. No ammonia slippage has been seen after using this sampling and analytical technique.

Sulfur Analysis of the Spent Sorbent

During the course of the testing, sorbent samples were withdrawn from the absorber and regenerator at various locations along the length of each respective reactor. While sampling sorbent from the absorber, the flue gas bypassed the reactor; for the regenerator, the reactor was purged with nitrogen before the samples were taken. A metal probe (thief) was inserted at the port and a vacuum drew the sample into a container. The probe was gradually moved back and forth within the vessel in an attempt to obtain a representative sample at a horizontal cross-section of the reactor. These samples were then analyzed for total sulfur content by using a LECO sulfur analyzer. After MBCUO-3, the absorber ports were enlarged to facilitate probe insertion and sample withdrawl during sampling. After MBCUO-5, samples could also be taken from the hoppers that were located before and after the regenerator and from the transport hopper. Caution must be used in interpreting these results since some locations prior to the change before MBCUO-6 may not have given a representative sample. An example of this is the original regenerator outlet location which was in reality a distance above where the regenerant (reducing agent) entered the reactor. Results of sulfur analyses can be found in Table 12.

For the MBCUO-2 and MBCUO-3 tests, the extent of regeneration was substantial with a high sorbent residence time and with an excess natural gas flow. The sulfur content on the regenerated sorbent was typically low. However, residual sulfur was always present on the sorbent and it can be speculated that the sulfur is bonded to the alumina substrate, as discussed by McCrea et al. (1970).

Sulfur Balances

Sulfur material recoveries in the summary tables are reported for the gas phase only. At steady-state, the sulfur dioxide in the flue gas that was removed by sorbent must equal the sulfur dioxide emitted in the regeneration step. Although MBCUO-2 did not monitor the flow of gas from the regenerator, sulfur material balances from subsequent testing were reasonable.

Regeneration Parametric Study -- Natural Gas: MBCUO-4

Most regeneration studied to date has been with natural gas. From past results and a more recent microbalance study, a temperature of 850°F is required with a sufficient residence time for an effective regeneration with methane (natural gas). For the purpose of this study, the initial baseline test was one chosen from MBCUO-3 with a sorbent flow of 0.75 lb/min (MBCUO-3-6). Criteria for this was that at these absorber process parameters, the utilization is high (near 60%) and would approach that which would occur in a commercial application.

Absorber process conditions were held constant throughout the tests with the realization that a regeneration parametric change would not only affect the regeneration results (e.g., gas and sorbent composition from the regenerator) but also the SO_2 removal efficiency of the absorber. Regeneration parameters that were investigated were the inlet CH_4/S molar ratio, sorbent residence time, and temperature.

It must be specified that this test was conducted with the UOP sorbent, but the supply of sorbent was exhausted at the end of the test. The residence time in the regenerator was decreased periodically during the test so that the sorbent extracted from the regenerator could be used as make-up sorbent that was required because of attrition. Therefore, it was impossible to repeat the initial baseline period (3-hr regenerator residence time) at the end of the test. Also, it was noted that the absorber pressure drop increased during parts of the test and a corresponding decrease in absorber SO2 removal would occur. This problem was avoided by periodically bypassing the flue gas around the reactor and then scrubbing the reactor retention screens by circulating sorbent through the bed for a 2-3 hour period. Visual inspection of the retention screens during the later post-test maintenance period revealed that small pieces of sorbent were caught in the exit retention screen. Also, note that before MBCUO-4, the overall particle size distribution of the sorbent had shifted. Sieve analysis of the unused fresh sorbent resulted in 99.9% retained on a 16-mesh screen; after MBCUO-3, 89.6% was retained on a 16-mesh screen.

Unlike Tests MBCUO-2 and MBCUO-3, the nitrogen purges in the inlet and outlet hoppers around the regenerator were terminated during this test. Thus the CH_4, SO_2, and CO_2 compositions should add up to 100%. These components were obtained from the continuous gas analyzers and are periodically checked by taking a volumetric gas sample and having it analyzed by gas chromatography. Comparisons are usually excellent.

Hydrogen regeneration was attempted during the last period of the test. However, instability of the temperature prohibited any meaningful test results.

Inlet CH_4/S Molar Ratio

This ratio is defined as the moles of natural gas flowing into the reactor divided by the sulfur on the sorbent. The flow of natural gas into the reactor was taken as 100% methane, whereas in actuality it is closer to 90%. Since the SO_2 removal efficiency was typically high, the moles of S was calculated from the total amount of SO_2 flowing into the absorber. This method of calculating the CH_4/S ratio has been used throughout the research effort. An excess of natural gas was present at all times and results from varying the ratio from 0.59 to 1.17 are shown in Figure 4. Results are from Periods MBCUO-4-3, MBCUO-4-2, and

MBCUO-4-1. It can been seen that as the molar ratio increases, the methane concentration in the regenerator offgas increases and the corresponding SO_2 concentration decreases because of the dilution effect of the methane. However, as the ratio approaches the stoichiometric amount required from the process chemistry (0.5/1), the activity of the sorbent in the absorber decreases. This would probably be magnified if the residence time were not 3-hr. Also, the sulfur on the sorbent out of the regenerator appears to be higher at the lower molar ratio.

Sorbent Residence Time

The impact of the residence time within the regenerator was also investigated. Residence times of 60 min (MBCUO-4-7), 120 min (MBCUO-4-4), and 180 min (MBCUO-4-1) were studied, and the results are shown in Figure 5. Attempts were made to hold constant all other parameters within the regenerator. From the results, it appears that as the residence time increases a better regeneration occurs as noted by a decreasing methane gas exit concentration and an increasing SO_2 concentration. The SO_2 removal efficiency in the absorber increased with increasing residence time; the residual sulfur on the sorbent decreased slightly with increasing residence time.

Temperature

The impact of temperature on regeneration is shown in two separate comparisons: at a 120 min residence time and at 850°F (MBCUO-4-4) and 937°F (MBCUO-4-6A); at a 60 min residence time and at 815°F (MBCUO-4-8) and 876°F (MBCUO-4-7). In the first case, the absorber activity after regeneration at the extremely high temperature of 937°F was lower (probably within the limits of uncertainty) than after the 850°F regeneration. This could indicate that at 850°F and 120 min residence time, the sorbent is being adequately regenerated or, that at the higher regeneration temperature, some irreversible deactivation of the sorbent occurred. It must be recognized that after the high temperature regeneration, the sulfur content on the sorbent was the lowest seen, but not too different than the 850°F regeneration (0.87 versus 0.93 wt%).

For the higher temperature regeneration, the contents of the gas stream leaving the regenerator were low with respect to SO_2, and the sulfur recovery was extremely low. Typically, when the regeneration temperature is 850°F, the temperature of the sorbent within the fluid bed heater -- immediately preceding the regenerator -- is near 1020°F. However, to obtain the higher temperature within the regenerator, the temperature in the fluid bed heater soared to near 1190°F. Some thermal decomposition of the copper sulfate occurred as indicated by the SO_2 analyzer on the exit stream to the fluid bed heater.

The other impact of temperature was determined at a residence time of 60 min and temperatures of 815°F and 876°F. The lower temperature adversely affected the regeneration as denoted in the higher concentration of methane in the exit gas stream at the lower temperature and the corresponding lower concentration of carbon dioxide. The absorber SO_2 removal was significantly lower (76.6

versus 83.5) and the sulfur content of the sorbent at the lower temperature was high (1.47 versus 1.02 wt%).

Regeneration Parametric Study -- Natural Gas and Hydrogen: MBCUO-5

A Grace sorbent that contained 7.0 wt% copper was used during this test. The initial test condition was identical to a previous test period with the UOP sorbent using natural gas as the regenerant. Parametric conditions for this base case were chosen to match a test from MBCUO-4. The effect of nitrogen dilution during natural gas regeneration was also studied. Additionally, hydrogen regeneration was investigated.

Prior to the test, a sliding thermocouple in a thermowell was installed in a radial position within the regenerator. This was to determine if significant radial thermal gradients occurred during hydrogen regeneration.

Toward the latter part of the test, the flue gas was produced by combusting the Illinois coal (Old Ben No. 24). Pluggage of the retention screens and/or the bed decreased the effectiveness of the moving-bed absorber. Certain information that pertained to the operation led to the conclusion that bed scrubbing (bypassing the flue gas around the absorber and then circulating sorbent through the bed for a 2-3 hr period) could reduce the pressure drop and return the overall system to the prior conditions. However, a rapid growth in the pressure drop across the absorber would continue to occur once flyash-laden flue gas was reintroduced, and the results are questionable, since steady-state conditions were difficult to attain.

Sorbent Comparison

The test period for comparison with the Grace sorbent was MBCUO-4-4 that used UOP sorbent at the following nominal conditions: absorber temperature of 750oF with 2250 ppm of SO_2 in 110 scfm of flue gas, sorbent flow of 0.75 lb/min, regenerator temperature of 850oF, natural gas-to-sulfur molar ratio of 1.17, and 120 min regenerator residence time. This test period was compared with MBCUO-5-1, MBCUO-5-4, and MBCUO-5-1B. These periods used the Grace sorbent; were at identical process conditions as the UOP sorbent; and were repeats during MBCUO-5.

Results indicated that the three tests in MBCUO-5 were nearly the same. Comparison of these with the UOP result indicates that the Grace sorbent was more reactive with respect to SO_2 removal than the UOP sorbent. This could be explained by the difference in copper content between the sorbents (6.4 versus 7.0%) and possible differences in the substrate material of the sorbents. Also, for the UOP sorbent, the composition of the exit gas from the regenerator was higher in CH_4 but lower in SO_2 as compared to the Grace results, although the differences in the sulfur content of the sorbent from the regenerator were not that significant.

Effect of Nitrogen Dilution

The impact of increasing the gas velocity in the regenerator was demonstrated in MBCUO-5-2. All conditions were nearly identical with MBCUO-5-1 (or MBCUO-5-4) except that an equal molar flow of nitrogen diluent was injected with the natural gas into the bottom of the regenerator. Results from both test periods indicate that SO_2 removal efficiency was about the same as well as the sulfur content on the sorbent. The dilution effects were seen in the regenerator exit gas concentrations, except for the unexplained methane composition. It could be speculated from the results that the diluent had negligible effect -- possibly the lower regenerant (reducing gas) partial pressure was offset by a decrease in bulk mass transfer limitations.

Hydrogen Regeneration

Four test periods during MBCUO-5 were devoted to hydrogen regeneration. The initial operation in going to hydrogen from methane was complicated because of the exothermicity of the hydrogen regeneration. Due to operational inexperience at this condition, the regenerator was run at an elevated temperature during the first test period. However, the next two periods were conducted at an 850°F regenerator temperature followed by a 750°F condition. Heater controls on the regenerator were observed frequently. All tests were at the same absorption conditions and used hydrogen at a 120 min sorbent residence time in the regenerator and at a 4.65 H_2/S molar ratio. The high concentration of water in the regenerator exit gas also caused some operational problems.

Methane versus hydrogen regeneration

Test period MBCUO-5-1B can be compared with MBCUO-5-5B. Conditions were approximately the same except that a nitrogen diluted hydrogen gas was used in the one period rather than natural gas. Results indicate that the sorbent reactivity was a little lower after the hydrogen regeneration, but this may fall within the range of uncertainty. The nitrogen dilution was used in the hydrogen test because of operational problems downstream of the regenerator. Without the added nitrogen dilution with the hydrogen flow, regenerator gas concentration results would be similar to that of MBCUO-5-5A, with about 85% of the exit gas as SO_2.

From MBCUO-5-5B, no excess hydrogen as well as any other type of gas (H_2S) was seen in the regenerator off-gas, as determined from gas chromatography. Also, the sulfur content on the sorbent from the regenerator was greater than in any previous testing. Duplicates were run confirming this.

Regenerator temperature

The impact of temperature of hydrogen regeneration can be seen in test periods MBCUO-5-5, MBCUO-5-5B, and MBCUO-5-7, where the temperatures were 962, 851, and 755°F respectively. Results from these tests indicate that the SO_2 removal efficiencies did not vary significantly and the concentration of SO_2 exiting the regenerator was near the same for all three cases. Again, no excess hydrogen was seen in the exit gas stream. Also, the sulfur content on the sorbent exiting the system was high in all these cases.

Regeneration Parametric Study -- Hydrogen and Natural Gas: MBCUO-6

The concerns of the CRADA partners with respect to synthesis gas (H_2 + CO) regeneration led to additional testing with hydrogen. Interest also exists in trying to maintain good regeneration at a low temperature. A systematic parametric study with hydrogen was proposed for MBCUO-6, with the first two test periods operating at a regeneration temperature about 700°F.

A major concern during the original hydrogen testing in MBCUO-5 and these two test periods in MBCUO-6 was that no excess hydrogen was seen in the regenerator off-gas. A batch test was proposed where volumetric gas samples were taken and hopefully hydrogen would be seen during the breakthrough. After MBCUO-6-2, this batch test was performed in the regenerator. A three hour regeneration with hydrogen at 700°F was conducted. (See Figure 6.) As detected by gas chromatography, hydrogen as well as H_2S was emitted from the reactor during the latter stages of regeneration. Some temperature excursions did occur during this batch test. The initial bed temperatures were around 600-700°F and zoomed as high as 1000°F because of the introduction of pure hydrogen. Also, an increase in pressure due to plugging in the regenerator offgas line led to a brief shutdown that was followed by a resumption of hydrogen flow. Sulfur concentrations were high on the regenerated sorbent.

Following the batch test, the sorbent was regenerated with natural gas (MBCUO-6-9) and was compared with baseline periods in test MBCUO-5 (5-1, 5-4, and 5-1B) to see if it had changed significantly. From a SO_2 removal efficiency perspective, it did not appear that sorbent reactivity decreased.

In MBCUO-6-11, MBCUO-6-13, and MBCUO-6-14, attempts were made to observe excess hydrogen exiting the regenerator by increasing hydrogen input to the regenerator. All attempts were unsuccessful in accomplishing this.

General

Pressure Drop Across the Absorber

Pressure drop measurements across the absorber are taken at various locations as shown in Figure 7. The circles in Figure 7 represent the pressure tap points. The tap points are about 1/4-in away from the absorber screen. There are 6 pressure taps within the sorbent bed: 2 taps at each top, middle, and bottom location in the bed. The taps across points 1-4 measure the overall absorber bed pressure drop. The taps across points 1-2 and 3-4 measure the pressure drops across the front and back retention screens, respectively.

Table 13 lists selected pressure drop measurements for MBCUO-4 to MBCUO-6. Pressure drop across the sorbent can be deduced by subtracting (dp 1-2) and (dp 3-4) from (dp 1-4). Note that the dp 1-4 is located only at the bottom of the bed and that in the table, the three measurement for this are for three **times** during which the measurements were taken. MBCUO-4 used natural gas-firing to produce the flue gas and was the last test with UOP sorbent. As stated earlier, the sorbent particle size distribution had shifted to smaller particles as compared to the initial material. Upon inspection of the reactor at the end of the test, sorbent particles were stuck in the retention screen, and this may explain the higher pressure drop across the bed throughout the test.

MBCUO-5 used natural gas-firing to produce the flue gas for the first part of the test and was the first test with a fresh Grace sorbent. Pressure drops were low during this part of the test. At the end of the testing, the flue gas was produced by burning coal. The high pressure drops indicate particulate accumulation within the absorber. MBCUO-6 used natural gas-firing to produce the flue gas and tested the same Grace sorbent that was used in MBCUO-5.

In all the tests, it appears that the pressure drop across the front screen is negligible; most of the pressure drop can be attributed to buildup within the bed and across the back retention screen. Flyash particles are trapped within the bed and cannot be removed. A new design for the retention screens will hopefully remedy this problem.

Attrition

Sorbent attrition rate is calculated for each test series from sorbent make-up added during a test. Attrition rates are shown in Table 14 together with hours of operation, number of hopper cycles, and accumulative sorbent inventory cycles. From the topical report of Pennline et al. (1995), it must be remembered that the prime contributor to sorbent attrition is the transport of the sorbent within the transport line from the hopper to the fluidized-bed heater.

The sorbent attrition rate is comparable to sorbent attrition during NOXSO life-cycle testing at PETC in 1989.

Uncertainty in Calculated Quantities

Analysis for uncertainty in the SO_2 and NO_x removal efficiency calculations is determined to insure that proper conclusions are made with respect to removal efficiencies.

SO_2 concentration data may be affected by the following factors. A numerical example is discussed in detail.

(1) Effect of SO_2 analyzer accuracy for the absorber

Inlet conc. +/-2% full scale
full scale: 5000 ppm
max. error = +/- 100 ppm

Outlet conc. +/-2% full scale
full scale: 1000 ppm
max. error = +/- 20 ppm

Assuming the inlet SO_2 concentration is measured at 2250 ppm, it could range from 2150 ppm to 2350 ppm.

If SO_2 removal is 99% or outlet SO_2 is measured at 22 ppm, it could range from (22-20) = 2 ppm to (22+20) = 42 ppm

The error bar for SO_2 removal efficiency based on analyzers readings would be

maximum = (2350 - 2)/2350 = 99.91%
minimum = (2150 - 42)/2150= 98.05%

The error bar would be from 98.05% to 99.91% with the apparent removal at 99%.

(2) Effect of oxygen analyzer accuracy

Error +/- 2% full scale
Full scale is 25%
O_2 reading is 5%

Assuming the O_2 measured concentrations are 5% for both absorber inlet and outlet, it could mean 4.5% to 5.5%.

Then, the possible air in-leakage contribution is

fraction = (0.055-0.045)/(0.21 - 0.045) = 0.01/0.165= 0.0606
possible error in ppm reading = 0.0606*2250 ppm = 136 ppm

Then the lowest calculated efficiency value is
[2150-42-(136)]/(2150-136) = 1972/2014 = 97.91%.

It is recognized that the analyzer is a major source of error in the removal efficiency calculations. However, this source of error is being minimized by frequent analyzer calibrations. Calibration gas is an independent source of standard; it is blended by high accuracy volumetric mixing.

The remaining source of error is the possible slight non-linearity between cal-gas concentration level and the actual flue gas concentration level. For example, if the cal-gas is 2500 ppm and the actual flue gas concentration is 2300 ppm a very slight non-linearity may be present.

It is recommended that there is no need to assign an error bar for the data points for the calculated SO_2 removal efficiencies. The same analysis is applicable to uncertainty in NO_x removal efficiency calculation.

It should also be noted that since the data are averaged over a time window, the standard deviation of the calculated value is available from the PETC computerized data file.

SUMMARY

A parametric study of the Moving-Bed Copper Oxide Process was conducted using the LCTS. The effects of various parameters on the absorption step of this flue gas cleanup technique were systematically investigated. High removals of SO_2 were obtained at most conditions. Removal efficiencies within the temperature range of 700-800°F did not vary significantly. A decrease in the flue gas flow rate, a decrease in the inlet SO_2 concentration, and an increase in the sorbent flow rate would all tend to enhance the SO_2 removal capabilities of the absorber.

Regeneration studies investigated the optimization of the natural gas regeneration step with respect to temperature, reducing gas stoichiometric ratio, and sorbent residence time. Optimal regeneration temperature with natural gas is near the reported 850°F temperature. As the CH_4/S molar ratio increases or the sorbent residence time increases, the regeneration improves.

RECOMMENDATIONS

Hydrogen regeneration requires additional investigations to elucidate the process chemistry. Findings by McCrea et al. (1970) and Bjornbom et al. (1995) indicate that more hydrogen than predicted by the simple copper sulfate/hydrogen reduction equation is needed due to the occurrence of side reactions. Also, regenerator artifacts, if any, must be identified. The possibility of elemental sulfur generated as a product of regeneration may exist at certain conditions. Although elemental sulfur formation could be detrimental pertaining to sorbent life, it could also be an advantage to the overall process. Future investigations with hydrogen will clarify the results to date.

With respect to the LCTS being able to handle flyash particulate loading, information from MBCUO-7 must be analyzed to determine the course of action with the larger-sized Alcoa sorbent to be tested in the future.

December 20, 1995

Summary of Test Conditions (Natural Gas Fire)

Test Condition MBCUO-2	1	2	2A	3
Test Date 1995	5/23	5/24	5/26	5/26
Hours on stream	38.9	16.4	15	15.8
Accumulat. sorbent cycle	29.1	30.6	32.0	33.7
ABSORBER (1 ft x 8 ft)				
Absorber temp.nominal, °F	750	750	750	750
Absorber temp.actual, °F	740	748	748	735
Flue gas, scfm	54.4	54.2	54.3	107.8
Sorbent resident time, min	344	172	172	172
Sorbent flow, lb/min	0.5	1.0	1.0	1.0
Inlet SO_2, ppm	2247	2252	2239	3059
Outlet SO_2, ppm	135	110	102	425
SO_2 removal, %	94	95	95.2	85.9
Inlet NOx, ppm	492	NA	NA	530
Outlet NOx, ppm	22	NA	NA	316
NOx removal, %	95.6	NA	NA	39.6
NH_3 flow, lb/h	0.048	0	0	0.044
NH_3/NOx mol ratio	0.8	NA	NA	0.75
REGENERATOR				
regn temp. nominal,°F	850	850	850	850
regn temp. actual, °F	871	878	877	863
Resi.time, min	180	180	180	180
NG flow, lb/h	0.3	0.3	0.6	1.6
NG/S mol ratio	1.165	1.165	2.34	2.99
Equivalence	2.33	2.33	4.68	5.98
H_2 flow, lb/h	0	0	0	0
H_2/S mol ratio				
Equivalence				
SO_2, %	24.5	25	19.6	22.1
CO_2, %	35.9	30.1	35.5	21.4
CH_4, %	9.2	0.5	9.2	51.7
Regn off-gas,ft^3/m (dry)	NA	NA	NA	NA
(total Cu)/S mol ratio	1.87	3.72	3.74	1.38
Cu utilization, %	50.2	25.6	25.5	62
Sulfur balance (gas phase), %	NA	NA	NA	NA
Unregenerated S, %	0.88	NA	0.98	NA

Table 1. Summary for Test MBCUO-2

Summary of Test Conditions (Natural Gas Fire)

Test Condition MBCUO-3	1	2	2A	1A	3	1B	4	5	6	7	8
Test Date 1995	6/13	6/14	6/15	6/15	6/16	6/16	6/17	6/18	6/18	6/19	6/20
Hours on stream	29.01	20.5	18.57	12.35	14.45	2.87	15.57	20.62	14.4	20.73	7.22
Accumulat. sorbent cycle	37.84	40.23	42.45	43.99	45.77	46.09	48.0	50.36	53.04	57.32	61.85
ABSORBER (1 ft x 8 ft)											
Absorber temp.nominal, °F	750	700	700	750	800	750	750	750	750	750	600
Absorber temp.actual, °F	755	700	705	749	800	749	750	755	738	756	591
Flue gas, scfm	107	107	107	107	107	107	107	107	107	107	106
Sorbent resident time, min	117	117	117	117	117	117	117	117	156	94	117
Sorbent flow, lb/min	1	1	1	1	1	1	1	1	0.75	1.25	1
Inlet SO_2, ppm	2237	2277	2255	2242	2223	2218	1500	3244	2261	2261	2249
Outlet SO_2, ppm	209	242	171	153	164	123	56	606	303	199	521
SO_2 removal, %	90.5	89.2	92.4	93.2	92.5	94.4	96.3	81.2	86.5	91.1	76.6
Inlet NOx, ppm	519	474	NA	523	494	NA	522	513	493	491	NA
Outlet NOx, ppm	19	23	NA	31	31	NA	42	31	39	32	NA
NOx removal, %	96.3	95.1	NA	94.1	93.6	NA	92	93.9	92	93.3	NA
NH_3 flow, lb/h	0.114	0.107	0	0.133	0.123	0	0.122	0.121	0.117	0.123	0
NH_3/NOx mol ratio	0.91	0.94	NA	1.06	1.04	NA	0.96	0.97	0.99	1.05	NA
REGENERATOR											
regn temp. nominal,°F	850	850	850	850	850	850	850	850	850	850	850
regn temp. actual, °F	850	855	863	861	861	878	870	846	888	874	841
Resi.time, min	180	180	180	180	180	180	180	180	180	180	180
NG flow, lb/h	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.82	0.6	0.6	0.6
NG/S mol ratio	1.183	1.246	1.238	1.183	1.19	1.198	1.47	1.115	1.172	1.17	1.19
Equivalence	2.36	2.49	2.48	2.366	2.38	2.4	2.94	2.23	2.344	2.34	2.38
H_2 flow, lb/h	0	0	0	0	0	0	0	0	0	0	0
H_2/S mol ratio											
Equivalence											
SO_2, %	31.5	30.0	30.9	30.9	32.0	23	24.3	36	33.7	33	31.4
CO_2, %	37.7	41.0	40.5	41.0	37.0	43	40	37	36.8	39.8	39.9
CH_4, %	8.7	13.7	4.4	5.0	5.5	4.8	2.2	12	14.8	2.8	5.9
Regn off-gas,ft^3/m (dry)	0.53	0.55	NA	NA	0.54	NA	NA	0.67	0.39	0.55	NA
(total Cu)/S mol ratio	1.88	1.84	1.9	1.91	1.92	1.93	2.85	1.32	1.42	2.37	1.92
Cu utilization, %	48.2	48.4	48.6	48.8	48.2	48.9	33.8	61.5	60.9	38.4	39.9
Sulfur balance (gas phase), %	-8.0	-9.4	NA	NA	-6.9	NA	NA	+2.4	-24.9	-1.4	NA
Unregenerated S, %	0.84	0.91	NA	NA	1.3	NA	1.13	1	1.02	1.04	1.04

Table 2. Summary for Test MBCUO-3

Summary of Test Conditions (Natural Gas Fire)

Test Condition MBCUO-4	1	2	3	4	6	6A	4A	7	8	9
Test Date 1995	7/18	7/19	7/20	7/22	7/23	7/24	7/25	7/26	7/27	7/28
Hours on stream	29.9	17.6	20.5	37.7	34.4	31.4	11.7	26.4	17.3	13.1
Accumulat. sorbent cycle	63.6	65.3	67.4	70.6	74.4	77	78.4	80.6	82.3	83.9
ABSORBER (1 ft x 8 ft)										
Absorber temp.nominal, °F	750	750	750	750	750	750	750	750	750	750
Absorber temp.actual, °F	757	752	746	752	750	751	750	751	748	752
Flue gas, scfm	110.7	111	110.9	110.5	110.3	112.5	112.5	112.4	112.4	112.2
Sorbent resident time, min	200	200	200	200	200	200	200	200	200	200
Sorbent flow, lb/min	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Inlet SO_2, ppm	2270	2270	2251	2243	2278	2256	2281	2235	2229	2220
Outlet SO_2, ppm	255	295	335	343	481	395	530	366	496	385
SO_2 removal, %	88.6	86.8	84.6	84.0	78.3	82.0	76.4	83.5	76.6	81.8
Inlet NOx, ppm	504	494	498	NA	NA	494	501	491	473	NA
Outlet NOx, ppm	17	26	25	NA	NA	18	25	27	11	NA
NOx removal, %	96.5	94.6	94.7	NA	NA	96.2	95	94.4	97.6	NA
NH_3 flow, lb/h	0.097	0.096	0.094	0	0	0.095	0.099	0.093	0.094	0
NH_3/NOx mol ratio	0.83	0.84	0.81	NA	NA	0.83	0.85	0.8	0.87	NA
REGENERATOR										
regn temp. nominal, °F	850	850	850	850	900	900	850	850	800	800
regn temp. actual, °F	839	851	845	850	934	937	881	876	815	785
Resi.time, min	180	180	180	120	120	120	120	60	60	60
NG flow, lb/h	0.6	0.45	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0
NG/S mol ratio	1.17	0.873	0.59	1.18	1.16	1.154	1.14	1.17	1.17	0
Equivalence	2.34	1.746	1.18	2.36	2.32	2.308	2.28	2.34	2.34	0
H_2 flow, lb/h	0	0	0	0	0	0	0	0	0	0.3
H_2/S mol ratio										5
Equivalence										2.5
SO_2, %	39.7	46.2	52.5	34.7	25.6	25.9	30.9	31.2	31.9	56.7
CO_2, %	41.9	46.1	42.6	39.6	37.7	38.3	37.8	34.1	24.0	0
CH_4, %	18.9	6.4	0.7	28.6	31.7	31.3	32.8	36.2	42.9	0
Regn off-gas, ft^3/m (dry)	0.416	0.382	0.103	0.392	0.267	0.349	0.36	0.387	0.411	NA
(total Cu)/S mol ratio	1.36	1.36	1.38	1.38	1.36	1.35	1.34	1.37	1.37	1.38
Cu utilization, %	65	64	62	60.6	57	60.7	57	61	56	59.4
Sulfur balance (gas phase), %	-8.4	-0.04	-68.1	-19.5	-59.1	-30	-29.6	-28.7	-35.2	NA
Unregenerated S, %	0.74	1.05	2.43	0.95	0.6	NA	NA	1.3	1.47	1.14

Table 3. Summary for Test MBCUO-4

Summary of Test Conditions (Natural Gas/Coal Firing)

GRACE SORBENT

Test Condition MBCUO-5	1	2	3	4	5	5A	5B	7	1A	1B	9A	10	11	12A	12B	12C
Test Date 1995	8/15	8/16	8/16	8/17	8/18	8/19	8/20	8/21	8/21	8/22	8/23	8/24	8/24	8/25	8/25	8/25
Hours on stream	24.33	17.23	9.42	9.08	23.93	49.42	20.03	9.72	13.87	15.27	13.22	8.05	12.1	5.53	1.77	1.77
Accumulat. sorbent cycle	2.5	4.7	5.9	7.2	9.8	14.2	16.7	17.9	19.5	21	22.8	24.1	25.6	26.4	26.8	27
ABSORBER (1 ft x 8 ft)																
Absorber temp.nominal, °F	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
Absorber temp.actual, °F	760	761	755	760	755	751	768	747	744	758	754	739	752	746	765	775
Flue gas, scfm	111	107	108	108	108	107	108	108	108	108	56	56	56	58	58	58
Sorbent resident time, min	195	195	195	195	195	195	195	195	195	195	146	146	146	146	146	146
Sorbent flow, lb/min	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	1	1	1	1	1	1
Inlet SO_2, ppm	2155	2207	2197	2336	2239	2261	2250	2254	2241	2237	2052	2117	2074	2201	2209	2229
Outlet SO_2, ppm	130	134	163	146	184	254	194	200	220	165	14	40	336	206	90	71
SO_2 removal, %	93.8	93.8	92.4	93.6	91.6	88.4	91.1	90.8	89.8	92.4	99.3	97.9	82.7	90.3	95.8	96.7
Inlet NOx, ppm	510	492	NA	503	NA	NA	497	500	NA	500	703	NA	649	NA	NA	NA
Outlet NOx, ppm	26	23	NA	42	NA	NA	50	24	NA	22	19	NA	NA	NA	NA	NA
NOx removal, %	94.8	95.2	NA	91.3	NA	NA	89.6	95.1	NA	95.4	97.1	NA	NA	NA	NA	NA
NH_3 flow, lb/h	0.104	0.093	0	0.089	0	0	0.085	0.098	0	0.096	0.07	0	0	0	0	0
NH_3/NOx mol ratio	0.83	0.79	0	0.73	0	0	0.72	0.83	0	0.83	0.73	0	0	0	0	0
REGENERATOR																
regn temp. nominal,°F	850	850	850	850	850	850	850	750	800	850	850	750	750	750	750	750
regn temp. actual, °F	857	851	849	855	962	820	851	755	797	847	869	752	786	777	772	781
Resi.time, min	120	120	120	120	120	120	120	120	120	120	90	90	90	90	90	90
NG flow, lb/h	0.6	0.6	0.3	0.6	0	0	0	0	0.6	0.6	0.28	0.28	0	0	0	0
NG/S mol ratio	1	1	0.5	1					1	1	1	1				
Equivalence	2	2	1	2					2	2	2	2				
H_2 flow, lb/h	0	0	0	0	0.3	0.3	0.3	0.3	0	0	0	0	0.14	0.15	0.3	0.45
H_2/S mol ratio					5	5	5	5					4.7	5	10	15
Equivalence					2.5	2.5	2.5	2.5					2.4	2.5	5	7.5
SO_2, %	42	27	50	42	22.6	84.8	14	16	47	43	22	0.7	20	13	29	33
CO_2, %	41	24	45	39	0	0	0	0	33.1	39.4	22	10	0	0	0	0
CH_4, %	11.5	12	0	12	0	0	0	0	17.6	9.4	0	23	0	0	0	0
Regn off-gas, ft^3/m (dry)	0.455	0.715	0.268	0.454	0.646	NA	1.179	1.17	NA	0.55	0.53	0.53	NA	NA	NA	NA
(total Cu)/S mol ratio	1.57	1.59	1.58	1.49	1.49	1.49	1.56	1.56	1.56	1.55	3.98	3.86	3.96	3.91	3.91	3.82
Cu utilization, %	60	59	58.5	62.8	61.5	59.3	58.4	58.2	57.7	59.6	24.9	25.4	20.9	23.1	24.5	25.3
Sulfur balance (gas phase), %	+2.7	+4.1	-25.6	+1.0	-20.7	NA	-11.3	-	-	-3.6	-	-	NA	NA	NA	NA
Unregenerated S, %	1.13	1.01	2.98	NA	1.69	2.01	1.85	1.68	2.3	0.73	NA	NA	NA	NA	NA	NA
Coal, lb/hr	0	0	0	0	0	0	0	0	0	0	30.71	30.80	30.73	0	0	0

Table 4. Summary for Test MBCUO-5

GRACE SORBENT

Summary of Test Conditions (Natural Gas Fire)

Test Condition MBCUO-6	1	2	9	10	11	13	14				
Test Date 1995	10/19	10/20	10/22	10/23	10/25	10/26	10/27				
Hours on stream	35.23	34.35	31.33	19.92	36.68	24.9	11.58				
Accumulat. sorbent cycle	32.6	37.6	40.3	43.2	48.1	50.9	52.9				
ABSORBER (1 ft x 8 ft)											
Absorber temp.nominal, °F	750	750	750	750	750	750	750				
Absorber temp.actual, °F	742	762	750	762	750	755	751				
Flue gas, scfm	106	109	109	110	110	110	108				
Sorbent resident time, min	146	146	195	146	146	146	146				
Sorbent flow, lb/min	1	1	0.75	1	1	1	1				
Inlet SO_2, ppm	2276	2290	2250	2245	2244	2296	341				
Outlet SO_2, ppm	334	122	130	102	128	172	3				
SO_2 removal, %	85.3	94.7	94.2	95.5	94.3	92.5	99.2				
Inlet NOx, ppm	NA	516	NA	NA	NA	NA	NA				
Outlet NOx, ppm	NA	18	NA	NA	NA	NA	NA				
NOx removal, %	NA	96.5	NA	NA	NA	NA	NA				
NH_3 flow, lb/h	0	0.126	0	0	0	0	0				
NH_3/NOx mol ratio	0	0.996	0	0	0	0	0				
REGENERATOR											
regn temp. nominal,°F	700	700	850	850	850	850	750				
regn temp. actual, °F	704	719	849	860	850	834	744				
Resi.time, min	60	60	120	120	120	120	120				
NG flow, lb/h	0	0	0.6	0.6	0	0	0				
NG/S mol ratio			1	1							
Equivalence			2	2							
H_2 flow, lb/h	0.15	0.30	0	0	0.45	0.6	0.3				
H_2/S mol ratio	2.5	5			7.5	10	5				
Equivalence	1.25	2.5			3.75	5	2.5				
SO_2, %	22.16	21.15	51.09	45.55	44.36	47.35	17.69				
CO_2, %	0.01	0	43.35	44.66	0	0	0.02				
CH_4, %	0.61	0.1	5.86	3.66	0.77	0.64	0.04				
Regn off-gas,ft^3/m (dry)	0.533	0.529	0.428	0.412	0.588	NA	0.234				
(total Cu)/S mol ratio	2.07	2	1.53	2.03	2.03	1.98	13.6				
Cu utilization, %	41.2	47.4	61.6	47	46.6	46.7	7.3				
Sulfur balance (gas phase), %	-31.5	-40.8	+11.6	-5.2	+36.2	NA	+19.6				
Unregenerated S, %	4.41	5.14	1.5	1.2	2.6	1.9	2.6				

Table 5. Summary for Test MBCUO-6

MBCUO-02	PARAMETER	TAG	E/U	1	2	3	4
COMBUSTOR FILE				COMB018	COMB019	COMB019	COMB020
	COMB AIR	FY-1	#/HR	430.5	430.6	430.5	430.4
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	0.00	0.00
	NATURAL GAS	FY-20	#/HR	22.85	22.81	22.80	22.80
	COAL	WKT-26	#/HR	0.00	0.00	0.00	0.00
	FEEDER WT	WT-26	LBS	0.00	0.00	0.00	0.00
	EXCESS AIR	SY-X	%XSA	12.92	12.19	12.19	12.16
	HEAT INPUT	BTU	BTU/HR	604572	606411	606194	606248
	FLUE GAS (M)	FY-15	#/HR	522.5	521.5	523.2	524.1
	FURNACE O2	AT-O2-0	%	4.28	3.97	4.03	3.96
	FURNACE P	PT-5	H2O	-1.02	-0.95	-1.03	-0.95
	COMB AIR P	PT-1	PSIG	4.48	4.58	4.67	4.55
	MOTIVE AIR P	PT-3	PSIG	106.06	107.66	107.74	107.94
	NATURAL GAS P	PT-20	PSIG	4.16	4.19	4.20	4.18
	FLUE GAS P	PT-15	-H20	5.27	5.17	5.29	5.07
	COOL H2O P	PT-25	PSIG	118.03	117.56	116.89	117.13
	THEOR AIR	SY-X	#THEOAIR	381.22	383.69	383.76	383.76
	FURNACE CO2	AT-CO2-0	PERCENT	9.73	9.96	9.89	10.01
	FURNACE CO	AT-CO-0	PPM	13.53	12.17	12.40	10.46
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	0.00	0.00
	FLUE GAS (V)	FY-15	SCFM	112.1	111.9	112.2	112.4
ABSORBER FILE				ABS026	ABS26&27	ABS26&27	ABS028
	INLET SO2	AT-SO2-1	PPM	2247	2252	2239	3069
	INLET NOX	AT-NOx-1	PPM	492	119	122	530
	INLET O2	AT-O2-1	PERCENT	4.62	4.33	4.38	4.35
	OUTLET SO2	AT-SO2-2	PPM	136	110	102	425
	OUTLET NOX	AT-NOx-2	PPM	22	111	116	316
	OUTLET O2	AT-O2-2	PERCENT	4.73	4.77	5.12	4.59
	NO SPIKE	FT-101	#/HR	0.11	0.00	0.00	0.13
	SO2 SPIKE	FT-102	#/HR	1.49	1.41	1.42	2.16
	NH3 SPIKE	FT-103	#/HR	0.048	0.000	0.000	0.044
	BED DP	PDT-19	H2O	0.79	0.95	1.15	2.81
	FLUE GAS (M)	FY-17	#/HR	263.7	262.9	263.3	502.5
	INLET P	PT-17	-H2O	5.98	5.92	5.99	6.57
	SCREEN DP	PDT-21	H2O	0.20	0.31	0.48	1.38
	GAS INLET	TE-18	DEG F	747	747	748	747
	GAS OUTLET	TE-21	DEG F	621	622	616	676
	SORB IN	TE-390	DEG F	733	748	742	758
	SORB OUT	TE-391	DEG F	683	729	726	722
	SO2 REMOVAL	SO2REF	PERCENT	94.0	95.0	95.2	85.9
	NOX REMOVAL	NOXREF	PERCENT	95.6	4.4	0.6	39.6
	FLUE GAS (V)	FY-17	SCFM	54.4	54.2	54.3	107.8
REGENERATOR FILE				REG026	REG26&27	REG26&27	REG028
	QUICK REP O2	AT-O2-4A	PERCENT	0.01	0.00	0.25	0.28
	REGEN SO2	AT-SO2-4	PERCENT	24.49	26.01	19.57	22.11
	REGEN CH4	AT-CH4-4	PERCENT	9.19	0.80	9.16	51.71
	REGEN CO2	AT-CO2-4	PERCENT	36.91	30.13	35.54	21.40
	REGEN H2S	AT-H2S-4	PERCENT	2.24	2.48	2.36	2.27
	REGEN O2	AT-O2-4B	PERCENT	0.44	6.73	0.03	0.11
	NATURAL GAS	FY-300	#/HR	0.30	0.30	0.60	1.60
	NITROGEN	FY-310	#/HR	0.00	0.00	0.00	0.00
	REGEN P	PT-390	H2O	1.02	3.35	5.80	14.27
	SORB LEVEL	LT-360	INCHES	21.23	46.83	45.71	45.74
	TSORB (2")	TE-381	DEG F	910	674	696	671
	TSORB (17")	TE-382	DEG F	840	823	836	832
	TSORB (32")	TE-383	DEG F	888	900	674	869
	TSORB (47")	TE-384	DEG F	846	913	903	879
	TGAS(EXIT)	TE-385	DEG F	796	763	760	768
	T OFFGAS	TE-386	DEG F	131	138	147	189
	T COND EX	TE-387	DEG F	92	78	58	55
	T INC EX	TE-200	DEG F	453	415	358	351
	INCIN O2	AT-O2-5	PERCENT	21.86	21.53	21.80	21.76
	INCIN SO2	AT-SO2-5	PPM	206	274	288	429
FLUID BED HEATER FILE				FBH026	FBH26&27	FBH26&27	FBH028
	TSORB(12")	TE-373	DEG F	1100	1074	1071	1075
	NATURAL GAS	FY-55	#/HR	6.03	6.32	6.27	6.42
	AHTR AIR (M)	FY-30	#/HR	272.8	278.5	280.0	279.1
	FBH VEL	SY-30	FT/SEC	3.00	3.00	3.00	3.00
	FBH O2	AT-O2-3	PERCENT	19.02	19.60	19.80	20.57
	TAHTR OUT	TE-370	DEG F	1395	1415	1394	1430
	T PLENUM	TE-372	DEG F	784	812	806	818
	TSORB(24")	TE-374	DEG F	1099	1071	1069	1072
	TVENT	TE-375	DEG F	982	961	948	958
	THUM OUT	TE-376	DEG F	325	325	325	325
	FBH PRES	PT-376	H2O	6.45	3.92	3.47	1.14
	BED DP	PDT-376	H2O	10.91	13.30	11.62	13.54
	PLENUM DP	PDT-377	H2O	9.27	9.57	9.57	9.71
	FBH NOX	AT-NOx-3	PPM	9.29	3.41	3.19	0.66
	FBH SO2	AT-SO2-3	PPM	2.21	0.00	0.00	6.43
	AHTR AIR (V)	FY-30	SCFM	59.8	61.0	61.4	61.2
	REG NGAS (V)	FY-300S	SCFM	0.11	0.11	0.22	0.58
	REG N2 (V)	FY-310S	SCFM	0.00	0.00	0.00	0.00
FLUID BED COOLER FILE				FBC026	FBC26&27	FBC26&27	FBC028
	FBC AIR VEL	SY-360	FT/SEC	3.00	3.00	3.00	3.00
	AIR (M)	FY-360	#/HR	181.2	186.9	190.9	188.4
	T PLENUM	TE-362	DEG F	1022	1007	937	905
	T LOWER	TE-363	DEG F	945	907	883	902
	BED DP	PDT-365	H2O	10.56	10.64	12.30	11.67
	PLENUM DP	PDT-367	H2O	6.57	11.70	23.66	20.35
	FBC PRES	PT-368	H2O	1.28	1.30	1.31	1.31
	T UPPER	TE-364	DEG F	946	906	886	904
	T HEATER	TE-361	DEG F	562	556	573	387
	T AIR	TE-360	DEG F	106	92	92	96
	AIR PRES	PT-360	PSIG	2.64	2.69	2.73	2.69
	AIR DP	FT-360	H2O	0.45	0.47	0.48	0.48
	INLET SO2(ADJ)	SO2REF	PPM	2388	2352	2345	3199
	OUTLET SO2(ADJ)	SO2REF	PPM	144	117	112	451
	INLET NOX(ADJ)	NOXREF	PPM	523	126	129	554
	OUTLET NOX(ADJ)	NOXREF	PPM	23	119	128	333
	AIR (V)	FY-360	SCFM	39.7	41.0	41.8	41.3
TEMPERATURE FILE				TEMP018	TEMP019	TEMP019	TEMP020
	COMB AIR T	TE-1	DEG F	102	94	87	96
	CO AIR HTR T	TE-3	DEG F	600	600	600	600
	MOT AIR T	TE-6	DEG F	81	75	64	69
	FUR REFR T	TE-4	DEG F	1741	1706	1694	1694
	FURN EXIT T	TE-9	DEG F	1120	1127	1123	1127
	TOT FGAS T	TE-15	DEG F	901	900	911	839
	ABS FGAS T	TE-18	DEG F	751	750	751	750
	HUM EXIT T	TE-27	DEG F	326	326	325	326
	BGHS TOP T	TE-29	DEG F	304	303	301	301
	BGHS BOT T	TE-30	DEG F	304	304	303	303
	ABS Z1 T	TIC-85	DEG F	750	750	750	750
	ABS Z2 T	TIC-88	DEG F	750	750	750	750
	ABS Z3 T	TIC-91	DEG F	750	750	750	750
	ABS Z4 T	TIC-94	DEG F	750	750	750	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750
	CW SUP T	TE-42	DEG F	117	107	101	106
	CW FUR EX T	TE-43	DEG F	147	139	132	137
	CW FGC EX T	TE-44	DEG F	97	94	77	88
	NAT GAS T	TE-20	DEG F	85	78	68	72

Table 6. Detailed Information for Test MBCUO-2

MBCUO-03	PARAMETER	TAG	E/U	1	2	3	4	5	6	7	8	9	10	11	12	13	14
COMBUSTOR FILE				COMB021	COMB022	COMB023	COMB023	COMB024	COMB025	COMB025	COMB026	COMB027	COMB027	COMB027	COMB028	COMB029	COMB029
	COMB AIR	FY-1	#/HR	438.5	438.5	438.6	438.5	438.3	438.6	438.5	438.5	438.6	438.4	438.4	439.3	438.3	406.2
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NATURAL GAS	FY-20	#/HR	22.79	22.80	22.81	22.78	22.80	22.80	22.80	22.80	22.80	22.80	22.80	22.84	22.84	21.30
	COAL	WKT-25	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FEEDER WT	WT-25	LBS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	EXCESS AIR	BY-X	%XSA	14.29	14.24	14.26	14.35	14.25	14.31	14.26	14.29	14.29	14.26	14.26	14.27	14.28	13.87
	HEAT INPUT	BTU	BTU/HR	613984	617031	617150	616585	616806	617081	617066	617006	617007	617032	617012	618202	618184	551851
	FLUE GAS (M)	FY-16	#/HR	536.4	535.5	535.2	534.6	533.9	532.9	534.9	536.6	531.9	535.5	533.4	534.4	535.0	499.9
	FURNACE O2	AT-O2-0	%	4.95	4.43	4.35	4.66	4.78	5.27	4.38	4.38	4.32	4.32	4.22	4.12	4.26	4.21
	FURNACE P	PT-5	H2O	-1.00	-1.05	-0.98	-1.01	-0.98	-1.04	-1.01	-1.00	-1.04	-1.00	-1.00	-0.99	-1.01	-1.05
	COMB AIR P	PT-1	PSIG	4.62	4.52	4.55	4.35	4.48	4.37	4.70	4.69	4.31	4.57	4.46	4.26	4.42	4.19
	MOTIVE AIR P	PT-3	PSIG	107.65	107.53	106.18	107.28	107.87	107.72	106.52	95.22	95.65	95.50	94.42	88.08	94.90	95.29
	NATURAL GAS P	PT-20	PSIG	4.17	4.19	4.19	4.17	4.16	4.13	4.22	4.22	4.12	4.22	4.22	4.16	4.20	4.23
	FLUE GAS P	PT-15	-H20	5.40	5.37	5.26	5.34	5.34	5.22	5.29	5.34	5.27	5.32	5.36	5.33	5.34	4.38
	COOL H2O P	PT-25	PSIG	116.72	116.66	116.58	117.13	116.88	117.16	116.43	116.33	117.43	116.51	116.75	117.29	116.64	116.66
	THEOR AIR	BY-X	#THEOAIR	383.66	383.75	383.81	383.41	383.70	383.74	383.74	383.71	383.72	383.74	383.72	384.46	384.45	358.45
	FURNACE CO2	AT-CO2-0	PERCENT	9.26	9.59	9.56	9.69	8.88	7.94	9.17	9.16	9.28	9.95	9.20	9.78	9.51	10.04
	FURNACE CO	AT-CO-0	PPM	10.30	7.61	11.71	10.96	11.82	9.97	11.88	9.93	9.94	10.17	9.86	10.38	9.92	9.85
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FLUE GAS (V)	FY-15	SCFM	114.8	114.9	114.8	114.7	114.5	114.3	114.7	115.1	114.1	114.9	114.4	114.6	114.8	107.2
ABSORBER FILE				ABS030	ABS031	ABS032	ABS032	ABS033	ABS035	ABS035	ABS036	ABS037	ABS037	ABS037	ABS038	ABS039	ABS039
	INLET SO2	AT-SO2-1	PPM	2237	2277	2265	2242	2223	2218	1500	3244	2252	2261	2261	2276	2277	2249
	INLET NOX	AT-NOx-1	PPM	519	474	101	523	494	106	522	513	104	493	491	75	74	87
	INLET O2	AT-O2-1	PERCENT	4.93	4.90	4.92	5.00	4.94	4.94	4.94	4.85	4.77	4.81	4.74	4.65	4.77	4.89
	OUTLET SO2	AT-SO2-2	PPM	209	242	171	153	164	123	56	606	206	303	199	639	128	521
	OUTLET NOX	AT-NOx-2	PPM	19	23	94	31	31	103	42	31	96	39	32	81	86	62
	OUTLET O2	AT-O2-2	PERCENT	5.21	5.15	4.97	5.03	5.30	5.09	5.04	4.96	4.76	4.97	4.92	4.80	4.88	5.02
	NO SPIKE	FT-101	#/HR	0.12	0.12	0.00	0.12	0.11	0.00	0.11	0.11	0.00	0.11	0.11	0.00	0.00	0.00
	SO2 SPIKE	FT-102	#/HR	1.46	1.46	1.46	1.46	1.46	1.46	0.87	2.39	1.50	1.50	1.50	1.50	1.50	1.38
	NH3 SPIKE	FT-103	#/HR	0.114	0.107	0.001	0.133	0.123	0.000	0.122	0.121	0.000	0.117	0.123	0.000	0.000	0.000
	BED DP	PDT-19	H2O	2.25	2.55	2.90	3.39	4.48	3.15	4.20	4.95	5.22	5.72	6.16	5.17	2.46	3.46
	FLUE GAS (M)	FY-17	#/HR	490.7	490.2	490.1	490.3	497.1	490.3	490.1	500.6	497.3	496.8	496.0	496.6	490.3	492.9
	INLET P	PT-17	-H2O	6.79	6.85	6.86	6.74	6.91	6.58	6.75	6.81	6.61	6.79	6.84	6.73	6.76	6.54
	SCREEN DP	PDT-21	H2O	0.85	0.97	0.96	1.10	1.82	1.39	1.88	1.28	1.19	1.27	1.65	0.64	1.10	0.98
	GAS INLET	TE-18	DEG F	748	690	690	747	799	742	747	748	747	748	747	747	747	597
	GAS OUTLET	TE-21	DEG F	679	637	633	676	719	673	670	685	675	671	676	667	672	552
	SORB IN	TE-390	DEG F	761	701	712	751	801	755	754	762	754	727	761	735	758	584
	SORB OUT	TE-391	DEG F	728	689	684	740	784	742	730	751	738	728	760	734	721	592
	SO2 REMOVAL	SO2REF	PERCENT	90.5	89.2	92.4	93.2	92.5	94.4	96.3	81.2	90.9	86.5	91.1	71.7	94.3	76.6
	NOX REMOVAL	NOXREF	PERCENT	96.3	95.1	5.8	94.1	93.6	3.6	92.0	93.9	5.5	92.0	93.3	0.0	0.0	5.2
	FLUE GAS (V)	FY-17	SCFM	107.1	107.0	107.0	107.1	106.6	107.1	107.0	107.4	106.6	107.2	106.8	106.9	107.1	106.7
REGENERATOR FILE				REG030	REG031	REG032	REG032	REG033	REG035	REG035	REG036	REG037	REG037	REG037	REG038	REG039	REG039
	QUICK REP O2	AT-O2-4A	PERCENT	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.41	0.19
	REGEN SO2	AT-SO2-4	PERCENT	31.50	30.26	30.79	31.64	31.88	23.26	24.07	36.19	33.01	33.71	29.06	22.41	27.90	31.44
	REGEN CH4	AT-CH4-4	PERCENT	8.71	13.73	5.05	4.49	5.47	4.85	2.22	11.96	2.84	14.35	4.89	13.17	5.30	5.87
	REGEN CO2	AT-CO2-4	PERCENT	37.72	40.00	40.00	39.45	37.73	40.00	39.94	37.24	39.83	36.77	39.02	35.92	40.00	39.99
	REGEN H2S	AT-H2S-4	PERCENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.06	0.00	0.17	1.10	0.34	0.00	0.15	0.19	0.01	0.01	0.13	1.46	0.01	0.18
	NATURAL GAS	FY-300	#/HR	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.62	0.60	0.60	0.60	0.60	0.60	0.60
	NITROGEN	FY-310	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN P	PT-380	H2O	3.84	4.12	3.35	3.80	6.34	3.69	2.91	5.70	4.28	4.26	3.47	2.51	9.16	2.51
	SORB LEVEL	LT-380	INCHES	46.77	46.38	46.04	42.91	45.16	46.20	42.67	45.64	39.27	35.19	56.20	46.10	44.81	39.26
	TSORB (2")	TE-381	DEG F	861	858	872	866	866	930	877	846	839	919	881	856	838	841
	TSORB (17")	TE-382	DEG F	822	829	842	838	839	875	848	829	862	869	853	843	849	859
	TSORB (32")	TE-383	DEG F	846	860	853	854	864	837	864	834	856	876	877	846	841	852
	TSORB (47")	TE-384	DEG F	872	883	883	887	884	872	889	879	882	887	885	880	884	812
	TGAS(EXIT)	TE-385	DEG F	751	763	767	769	766	765	765	787	773	834	750	769	763	776
	T OFFGAS	TE-386	DEG F	164	167	160	162	163	167	162	173	169	160	161	169	164	165
	T COND EX	TE-387	DEG F	65	57	60	66	69	76	61	60	79	61	63	82	70	62
	T INC EX	TE-200	DEG F	401	392	411	443	450	495	427	420	479	426	421	434	424	443
	INCIN O2	AT-O2-5	PERCENT	19.84	19.78	20.52	20.41	21.52	21.32	21.53	19.75	19.64	20.82	20.29	20.11	19.77	19.68
	INCIN SO2	AT-SO2-5	PPM	430	357	373	375	373	261	264	0	759	346	376	297	325	346
FLUID BED HEATER FILE				FBH030	FBH031	FBH032	FBH032	FBH033	FBH035	FBH035	FBH036	FBH037	FBH037	FBH037	FBH038	FBH039	FBH039
	TSORB(12")	TE-373	DEG F	1024	1023	1025	1026	1025	1026	1026	1025	1026	1025	1024	1025	1025	1025
	NATURAL GAS	FY-55	#/HR	5.78	5.83	5.93	5.69	5.75	6.02	5.84	5.96	5.69	5.82	5.87	5.65	5.80	5.88
	AHTR AIR (M)	FY-30	#/HR	287.2	287.7	289.8	288.4	291.7	290.0	291.7	290.8	288.3	289.1	286.6	287.4	288.4	288.0
	FBH VEL	SY-30	FT/SEC	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	FBH O2	AT-O2-3	PERCENT	20.93	20.88	20.81	20.82	20.81	20.86	20.90	20.98	20.93	20.85	20.99	21.06	20.99	21.00
	TAHTR OUT	TE-370	DEG F	1298	1301	1313	1315	1287	1336	1293	1311	1298	1293	1314	1290	1302	1313
	T PLENUM	TE-372	DEG F	711	731	737	736	732	734	735	745	745	741	763	720	742	738
	TSORB(24")	TE-374	DEG F	1020	1020	1021	1020	1021	1021	1021	1021	1020	1021	1020	1021	1022	1020
	TVENT	TE-375	DEG F	914	905	906	901	902	914	901	910	900	926	904	903	903	896
	THUM OUT	TE-376	DEG F	500	500	500	500	498	500	500	500	500	500	500	500	500	500
	FBH PRES	PT-376	H2O	4.92	5.01	4.86	4.80	4.73	4.81	4.84	4.02	4.68	2.60	3.11	1.76	1.60	2.02
	BED DP	PDT-376	H2O	10.11	9.30	9.70	9.68	9.14	11.07	8.88	11.03	9.43	16.06	11.56	11.76	11.94	11.86
	PLENUM DP	PDT-377	H2O	9.41	9.54	9.62	9.57	9.53	9.67	9.61	9.72	9.42	9.55	9.53	9.34	9.58	9.54
	FBH NOX	AT-NOx-3	PPM	0.96	3.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FBH SO2	AT-SO2-3	PPM	0.01	1.51	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
	AHTR AIR (V)	FY-30	SCFM	62.9	63.1	63.5	63.4	63.9	63.6	63.9	63.7	63.2	63.4	62.8	63.0	63.2	63.1
	REG NGAS (V)	FY-300S	SCFM	0.22	0.22	0.22	0.22	0.22	0.22	0.18	0.30	0.22	0.22	0.22	0.22	0.22	0.22
	REG N2 (V)	FY-310S	SCFM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FLUID BED COOLER FILE				FBC030	FBC031	FBC032	FBC032	FBC033	FBC035	FBC035	FBC036	FBC037	FBC037	FBC037	FBC038	FBC039	FBC039
	FBC AIR VEL	SY-360	FT/SEC	3.01	3.00	3.00	3.00	3.01	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	AIR (M)	FY-360	#/HR	183.1	198.3	194.6	187.2	178.4	184.9	187.3	185.9	184.8	184.9	187.2	184.6	184.9	220.1
	T PLENUM	TE-362	DEG F	965	797	855	961	1089	981	951	942	934	987	914	960	949	642
	T LOWER	TE-363	DEG F	931	826	860	911	990	930	920	928	921	926	897	919	922	700
	BED DP	PDT-365	H2O	10.89	11.02	11.87	13.05	10.63	11.14	10.67	10.28	11.03	14.85	11.22	12.90	12.07	12.29
	PLENUM DP	PDT-367	H2O	6.89	6.96	6.96	7.02	6.98	6.94	6.90	6.84	6.85	6.90	6.83	6.82	6.55	6.80
	FBC PRES	PT-366	H2O	1.87	1.97	1.87	1.80	1.72	1.65	1.91	1.89	1.73	1.63	1.60	1.74	1.67	1.64
	T UPPER	TE-364	DEG F	933	827	861	912	991	931	921	929	923	927	899	920	923	702
	T HEATER	TE-361	DEG F	505	425	435	520	662	576	510	498	497	538	486	509	502	340
	T AIR	TE-360	DEG F	92	89	92	111	109	113	91	88	114	95	97	112	101	104
	AIR PRES	PT-360	PSIG	2.77	2.76	2.77	2.62	2.56	2.64	2.80	2.80	2.80	2.74	2.66	2.58	2.66	2.62
	AIR DP	FT-360	H2O	0.45	0.52	0.50	0.48	0.43	0.47	0.46	0.45	0.48	0.46	0.47	0.48	0.48	0.66
	INLET SO2(ADJ)	SO2REF	PPM	2428	2462	2439	2439	2409	2404	1626	3497	2418	2430	2421	2423	2441	2429
	OUTLET SO2(ADJ)	SO2REF	PPM	231	266	186	166	181	135	61	658	220	329	218	687	138	547
	INLET NOX(ADJ)	NOXREF	PPM	562	512	109	569	535	117	566	553	111	530	526	80	79	94
	OUTLET NOX(ADJ)	NOXREF	PPM	22	25	102	34	34	113	45	34	105	42	35	87	83	89
	AIR (V)	FY-360	SCFM	40.1	43.5	42.7	41.0	39.1	40.5	41.1	40.7	40.6	40.6	41.0	40.5	40.5	48.3
TEMPERATURE FILE				TEMP021	TEMP022	TEMP023	TEMP023	TEMP024	TEMP025	TEMP025	TEMP026	TEMP027	TEMP027	TEMP027	TEMP028	TEMP029	TEMP029
	COMB AIR T	TE-1	DEG F	93	92	94	116	111	119	92	90	118	97	99	117	105	110
	CO AIR HTR T	TE-3	DEG F	650	675	675	675	675	675	675	675	675	675	675	675	675	650
	MOT AIR T	TE-6	DEG F	67	64	68	80	76	82	68	63	84	65	70	82	72	73
	FUR REFR T	TE-4	DEG F	1767	1637	1624	1620	1626	1626	1621	1626	1634	1622	1626	1609	1606	1595
	FURN EXIT T	TE-9	DEG F	1165	1165	1172	1181	1170	1171	1163	1163	1174	1166	1171	1186	1181	1064
	TOT FGAS T	TE-15	DEG F	839	780	779	830	904	830	841	841	837	841	840	838	840	663
	ABS FGAS T	TE-19	DEG F	750	700	700	746	802	748	750	750	750	750	750	750	750	600
	HUM EXIT T	TE-27	-DEG F	385	385	386	387	385	385	385	385	385	385	385	385	385	379
	BGHS TOP T	TE-29	DEG F	354	354	354	356	356	357	356	356	356	356	356	357	355	347
	BGHS BOTT T	TE-30	DEG F	357	357	356	356	358	356	356	356	359	358	358	358	358	350
	ABS Z1 T	TIC-85	DEG F	750	701	699	748	801	753	750	750	750	750	750	750	750	595
	ABS Z2 T	TIC-88	DEG F	750	704	701	738	802	753	750	750	750	750	751	750	750	601
	ABS Z3 T	TIC-91	DEG F	750	700	701	751	800	750	750	750	750	750	750	750	750	600
	ABS Z4 T	TIC-94	DEG F	750	700	700	750	800	750	750	750	750	750	750	750	750	600
	ABS Z5 T	TIC-97	DEG F	750	700	700	750	800	748	750	750	750	750	750	750	750	600
	CW SUP T	TE-42	DEG F	95	100	99	107	109	107	101	105	112	104	106	115	106	103
	CW FUR EXT	TE-43	DEG F	129	132	133	142	143	143	136	138	147	138	138	150	140	135
	CW FGC EXT	TE-44	DEG F	94	88	98	99	103	112	91	89	110	84	87	98	81	88
	NAT GAS T	TE-20	DEG F	70	67	71	83	81	86	69	68	88	70	73	88	74	75

Table 7. Detailed Information for Test MBCUO-3

MBCUO-04	PARAMETER	TAG	E/U	1	2	3	4	5	6	7	8	9	10
COMBUSTOR FILE				COMB030	COMB031	COMB032	COMB033	COMB034	COM35&36	COMB037	COMB038	COMB039	COMB040
	COMB AIR	FY-1	#/HR	422.0	421.9	422.0	422.0	421.9	430.4	430.4	430.4	430.3	430.4
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NATURAL GAS	FY-20	#/HR	21.88	21.88	21.88	21.88	21.88	22.30	22.30	22.30	22.30	22.31
	COAL	WKT-25	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FEEDER WT	WT-25	LBS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	EXCESS AIR	SY-X	%XSA	14.59	14.55	14.59	14.58	14.55	14.69	14.69	14.66	14.68	14.64
	HEAT INPUT	BTU	BTU/HR	572517	572583	572494	572525	572559	583473	583366	583390	583406	583616
	FLUE GAS (M)	FY-15	#/HR	516.1	517.4	517.2	515.4	514.3	524.5	524.2	524.1	523.9	523.0
	FURNACE O2	AT-O2-0	%	4.24	4.34	4.42	4.24	4.26	4.24	4.25	4.30	4.35	4.30
	FURNACE P	PT-5	H2O	-0.96	-0.90	-0.90	-1.01	-1.00	-1.03	-0.90	-0.97	-0.90	-0.97
	COMB AIR P	PT-1	PSIG	4.35	4.59	4.65	4.49	4.36	4.40	4.35	4.31	4.36	4.48
	MOTIVE AIR P	PT-3	PSIG	96.40	96.42	97.48	96.61	96.76	96.75	97.14	96.97	96.16	96.46
	NATURAL GAS P	PT-20	PSIG	4.17	4.21	4.21	4.19	4.18	4.17	4.17	4.16	4.18	4.19
	FLUE GAS P	PT-15	-H20	4.99	5.03	5.06	5.01	5.00	5.18	5.11	5.10	5.12	5.08
	COOL H2O P	PT-25	PSIG	116.28	113.93	113.05	114.87	114.98	114.08	113.02	113.42	111.87	111.39
	THEOR AIR	SY-X	#THEOAIR	368.29	368.33	368.29	368.30	368.32	375.35	375.27	375.29	375.29	375.45
	FURNACE CO2	AT-CO2-0	PERCENT	9.46	9.56	9.32	9.44	9.49	9.53	9.58	9.40	9.43	9.49
	FURNACE CO	AT-CO-0	PPM	11.96	13.60	13.64	11.79	11.97	11.68	12.07	11.87	12.17	12.07
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FLUE GAS (V)	FY-15	SCFM	110.7	111.0	110.9	110.5	110.3	112.5	112.5	112.4	112.4	112.2
ABSORBER FILE				ABS042	ABS043	ABS044	ABS045	ABS046	ABS047	ABS048	ABS049	ABS050	ABS051
	INLET SO2	AT-SO2-1	PPM	2270	2270	2251	2243	2278	2256	2281	2236	2229	2220
	INLET NOX	AT-NOx-1	PPM	504	494	498	76	77	494	501	491	473	80
	INLET O2	AT-O2-1	PERCENT	4.91	5.01	5.00	4.83	4.82	4.76	4.90	4.81	4.81	4.88
	OUTLET SO2	AT-SO2-2	PPM	255	295	335	343	461	385	530	366	496	365
	OUTLET NOX	AT-NOx-2	PPM	17	26	25	72	74	18	25	27	11	74
	OUTLET O2	AT-O2-2	PERCENT	5.08	5.27	5.55	5.53	5.23	5.15	5.06	4.90	5.56	5.65
	NO SPIKE	FT-101	#/HR	0.11	0.11	0.11	0.00	0.00	0.11	0.11	0.11	0.14	0.00
	SO2 SPIKE	FT-102	#/HR	1.45	1.47	1.46	1.43	1.46	1.46	1.46	1.46	1.46	1.46
	NH3 SPIKE	FT-103	#/HR	0.097	0.096	0.094	0.000	0.000	0.085	0.090	0.083	0.084	0.000
	BED DP	PDT-19	H2O	3.15	3.99	4.34	5.10	5.90	4.46	4.76	3.90	3.49	3.73
	FLUE GAS (M)	FY-17	#/HR	499.5	500.1	500.7	498.5	497.4	507.2	507.9	506.7	507.0	507.9
	INLET P	PT-17	-H2O	6.45	6.56	6.56	6.44	6.43	6.63	6.60	6.56	6.62	6.50
	SCREEN DP	PDT-21	H2O	1.70	1.63	1.46	1.54	1.60	1.70	0.63	1.26	1.06	0.48
	GAS INLET	TE-18	DEG F	747	747	747	747	747	747	747	747	747	746
	GAS OUTLET	TE-21	DEG F	660	665	662	659	660	665	658	664	663	650
	SORB IN	TE-390	DEG F	766	757	745	758	753	754	752	755	746	758
	SORB OUT	TE-391	DEG F	712	707	706	706	711	707	709	704	700	699
	SO2 REMOVAL	SO2REF	PERCENT	86.8	86.8	84.6	84.0	79.3	82.0	76.4	83.5	76.6	81.8
	NOX REMOVAL	NOXREF	PERCENT	96.5	94.6	94.7	1.3	1.0	96.2	95.0	94.4	97.6	2.1
	FLUE GAS (V)	FY-17	SCFM	107.1	107.3	107.4	106.9	106.7	108.8	108.9	108.7	108.7	108.9
REGENERATOR FILE				REG042	REG043	REG044	REG045	REG046	REG047	REG048	REG049	REG050	REG051
	QUICK REP O2	AT-O2-4A	PERCENT	0.00	0.00	0.11	0.02	0.07	0.02	0.00	0.00	0.01	0.00
	REGEN SO2	AT-SO2-4	PERCENT	39.75	46.23	52.55	34.69	26.56	26.87	30.94	31.17	31.94	56.74
	REGEN CH4	AT-CH4-4	PERCENT	18.81	6.35	0.71	28.64	31.69	31.27	32.90	36.22	42.88	0.02
	REGEN CO2	AT-CO2-4	PERCENT	41.95	46.14	42.55	39.63	37.69	39.32	37.78	34.08	23.96	0.00
	REGEN H2S	AT-H2S-4	PERCENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.13	0.01	0.30	0.14	0.16	0.09	0.24	0.25	0.18	0.45
	NATURAL GAS	FY-300	#/HR	0.60	0.45	0.30	0.60	0.60	0.60	0.60	0.60	0.60	0.88
	NITROGEN	FY-310	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN P	PT-380	H2O	6.39	3.95	7.07	-0.91	-0.39	-1.31	-1.86	-1.79	-1.73	-0.60
	SORB LEVEL	LT-380	INCHES	36.96	35.93	37.21	25.24	23.26	23.23	22.27	10.67	12.64	11.77
	TSORB (2")	TE-381	DEG F	846	851	839	869	964	968	902	863	792	798
	TSORB (17")	TE-382	DEG F	816	827	830	835	911	915	945	893	635	790
	TSORB (32")	TE-383	DEG F	855	875	867	857	937	937	896	873	619	777
	TSORB (47")	TE-384	DEG F	829	836	819	820	884	885	867	824	776	735
	TGAS(EXIT)	TE-385	DEG F	802	802	795	787	838	840	814	778	738	706
	T OFFGAS	TE-386	DEG F	155	159	90	145	1200	136	125	131	123	270
	T COND EX	TE-387	DEG F	79	83	72	76	76	84	84	85	82	80
	T INC EX	TE-200	DEG F	431	416	420	425	426	442	419	438	435	440
	INCIN O2	AT-O2-5	PERCENT	15.96	15.26	19.53	19.06	19.12	19.32	19.40	19.66	19.70	19.74
	INCIN SO2	AT-SO2-5	PPM	347	379	144	241	226	271	306	434	413	430
FLUID BED HEATER FILE				FBH042	FBH043	FBH044	FBH045	FBH046	FBH047	FBH048	FBH049	FBH050	FBH051
	TSORB(12")	TE-373	DEG F	1026	1026	1024	1090	1169	1193	1110	1078	1000	673
	NATURAL GAS	FY-55	#/HR	5.67	5.84	5.82	6.01	6.60	6.60	6.10	5.90	5.50	3.87
	AHTR AIR (M)	FY-30	#/HR	286.1	288.0	288.8	274.6	258.3	255.7	271.3	276.9	293.0	380.6
	FBH VEL	SY-30	FT/SEC	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	FBH O2	AT-O2-3	PERCENT	21.03	21.02	21.02	20.96	20.93	12.66	16.41	14.36	15.10	17.94
	TAHTR OUT	TE-370	DEG F	1303	1307	1294	1388	1565	1570	1418	1360	1248	726
	T PLENUM	TE-372	DEG F	663	671	670	781	874	886	804	787	708	525
	TSORB(24")	TE-374	DEG F	1020	1020	1020	1066	1185	1188	1106	1073	996	669
	TVENT	TE-375	DEG F	907	912	904	963	1034	1048	977	958	889	623
	THUM OUT	TE-376	DEG F	500	500	500	500	500	500	500	500	500	500
	FBH PRES	PT-376	H2O	5.26	5.79	2.92	1.79	1.27	5.23	5.73	5.39	6.00	8.41
	BED DP	PDT-376	H2O	9.62	11.30	11.84	11.98	11.59	8.24	9.48	8.37	8.99	9.51
	PLENUM DP	PDT-377	H2O	9.42	9.68	9.59	9.26	8.92	8.91	9.14	9.17	9.42	10.48
	FBH NOX	AT-NOx-3	PPM	0.00	0.00	0.00	0.00	0.00	27.50	6.45	20.79	16.04	6.75
	FBH SO2	AT-SO2-3	PPM	0.02	0.00	0.00	0.00	0.00	352.72	120.26	116.53	12.07	1.60
	AHTR AIR (V)	FY-30	SCFM	62.72	63.13	63.31	60.19	56.17	56.04	59.46	60.69	64.22	83.42
	REG NGAS (V)	FY-300S	SCFM	0.22	0.16	0.11	0.22	0.22	0.22	0.22	0.22	0.22	0.32
	REG N2 (V)	FY-310S	SCFM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FLUID BED COOLER FILE				FBC042	FBC043	FBC044	FBC045	FBC046	FBC047	FBC048	FBC049	FBC050	FBC051
	FBC AIR VEL	SY-360	FT/SEC	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	AIR (M)	FY-360	#/HR	183.9	186.3	188.6	184.3	183.4	183.9	186.8	185.4	186.6	183.6
	T PLENUM	TE-362	DEG F	989	977	976	992	1001	974	996	976	1023	976
	T LOWER	TE-363	DEG F	919	909	896	922	924	919	903	909	906	926
	BED DP	PDT-365	H2O	12.07	12.47	10.41	11.18	10.35	9.90	12.24	10.46	9.96	10.07
	PLENUM DP	PDT-367	H2O	6.56	7.01	7.13	6.94	6.70	6.67	7.12	6.90	7.07	7.01
	FBC PRES	PT-366	H2O	1.84	1.79	1.78	1.69	1.74	1.70	1.73	1.86	1.72	1.78
	T UPPER	TE-364	DEG F	921	911	897	923	925	920	905	911	907	929
	T HEATER	TE-361	DEG F	523	522	487	524	537	503	596	486	548	388
	T AIR	TE-360	DEG F	112	97	91	102	108	107	109	115	110	101
	AIR PRES	PT-360	PSIG	2.57	2.68	2.73	2.63	2.59	2.60	2.59	2.56	2.60	2.65
	AIR DP	FT-360	H2O	0.47	0.47	0.47	0.46	0.47	0.47	0.46	0.46	0.48	0.46
	INLET SO2(ADJ)	SO2REF	PPM	2457	2471	2449	2414	2451	2417	2451	2404	2396	2399
	OUTLET SO2(ADJ)	SO2REF	PPM	279	327	377	385	531	434	579	397	562	437
	INLET NOX(ADJ)	NOXREF	PPM	545	538	542	82	82	529	539	528	507	86
	OUTLET NOX(ADJ)	NOXREF	PPM	19	29	28	81	82	20	27	30	12	84
	AIR (V)	FY-360	SCFM	40.3	40.8	41.3	40.4	40.2	40.3	40.9	40.6	40.9	40.2
TEMPERATURE FILE				TEMP030	TEMP031	TEMP032	TEMP033	TEMP034	TEM35&36	TEMP037	TEMP038	TEMP039	TEMP040
	COMB AIR T	TE-1	DEG F	115	97	90	101	109	108	111	119	114	101
	CO AIR HTR T	TE-3	DEG F	500	500	500	500	500	500	500	500	500	500
	MOT AIR T	TE-6	DEG F	81	66	64	75	81	81	78	82	78	76
	FUR REFR T	TE-4	DEG F	1556	1581	1578	1586	1584	1590	1594	1595	1592	1594
	FURN EXIT T	TE-9	DEG F	1115	1110	1118	1115	1122	1134	1130	1136	1131	1131
	TOT FGAS T	TE-15	DEG F	850	855	854	852	851	850	848	849	849	848
	ABS FGAS T	TE-16	DEG F	750	750	750	750	750	750	750	750	750	749
	HUM EXIT T	TE-27	DEG F	385	385	385	385	385	385	385	385	385	385
	SGHS TOP T	TE-29	DEG F	354	356	357	356	357	188	160	161	318	356
	SGHS BOT T	TE-30	DEG F	357	355	358	358	357	192	165	159	336	358
	ABS Z1 T	TIC-85	DEG F	750	750	750	750	750	750	750	750	750	750
	ABS Z2 T	TIC-88	DEG F	750	750	750	750	750	750	750	750	750	750
	ABS Z3 T	TIC-91	DEG F	750	750	750	750	750	750	750	750	750	750
	ABS Z4 T	TIC-94	DEG F	750	750	750	750	750	750	750	750	750	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750	750	750	750	750	750	750
	CW SUP T	TE-42	DEG F	109	102	100	109	113	112	113	111	110	106
	CW FUR EX T	TE-43	DEG F	141	134	132	142	144	144	145	144	141	136
	CW FGC EX T	TE-44	DEG F	93	90	77	85	86	97	92	97	90	65
	NAT GAS T	TE-20	DEG F	83	69	67	77	82	83	80	85	80	77

Table 8. Detailed Information for Test MBCUO-4

MBCUO-05	PARAMETER	TAG	E/U	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
COMBUSTOR FILE				COMB041	COMB042	COMB043	COMB044	COMB045	COMB046	COMB047	COMB048	COMB049	COMB049	COMB050	COMB051	COMB052	COMB053	COMB053	COMB053
	COMB AIR	FY-1	#/HR	446.9	446.6	447.1	446.8	446.8	446.9	446.8	447.9	446.9	444.8	439.2	438.1	439.0	432.8	432.8	432.7
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.19	16.45	15.92	0.00	0.00	0.00
	NATURAL GAS	FY-20	#/HR	22.73	22.71	22.71	22.72	22.72	22.71	22.72	22.68	22.72	22.71	4.87	4.87	4.86	22.72	22.72	22.72
	COAL	WKT-25	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.71	30.80	30.73	0.00	0.00	0.00
	FEEDER WT	WT-25	LBS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.71	46.12	46.30	49.52	49.19	48.84
	EXCESS AIR	SY-X	%XSA	16.80	16.86	16.90	16.86	16.86	16.94	16.86	17.37	17.40	16.36	22.77	22.81	22.49	13.20	13.22	13.16
	HEAT INPUT	BTU	BTU/HR	594647	594166	594011	594361	594336	594120	594418	593278	594368	594294	569405	569600	569666	594337	594253	594364
	FLUE GAS (M)	FY-15	#/HR	536.1	537.0	537.4	539.7	536.7	536.0	537.4	539.4	543.6	540.4	544.8	547.7	544.5	522.1	523.1	526.8
	FURNACE O2	AT-O2-0	%	4.46	4.32	4.41	4.48	4.54	4.60	4.67	4.73	4.82	4.87	3.98	3.82	5.83	4.21	4.30	4.30
	FURNACE P	PT-5	H2O	-0.97	-1.01	-1.03	-1.00	-0.96	-0.97	-1.01	-0.99	-1.02	-0.97	-1.06	-0.97	-0.99	-1.01	-0.97	-0.99
	COMB AIR P	PT-1	PSIG	4.20	4.36	4.27	4.46	4.30	4.27	4.26	4.29	4.49	4.38	4.42	4.86	4.18	4.19	4.29	4.34
	MOTIVE AIR P	PT-3	PSIG	95.44	96.68	93.91	96.48	96.84	96.32	95.07	96.82	96.56	97.18	97.64	98.06	95.44	96.13	95.97	95.76
	NATURAL GAS P	PT-20	PSIG	4.13	4.17	4.14	4.19	4.15	4.14	4.15	4.14	4.15	4.13	4.63	4.63	4.58	4.13	4.14	4.15
	FLUE GAS P	PT-15	-H20	5.31	5.38	5.42	5.46	5.39	5.27	5.38	5.36	5.46	5.41	6.07	5.88	5.79	5.72	5.82	5.72
	COOL H2O P	PT-25	PSIG	117.02	115.80	116.41	114.54	115.40	115.39	115.21	114.54	113.30	113.69	113.25	112.09	114.64	112.11	111.38	110.90
	THEOR AIR	SY-X	#THEOAIR	382.55	382.22	382.13	382.35	382.33	382.19	382.37	381.63	382.33	382.29	370.97	372.10	371.48	382.35	382.29	382.36
	FURNACE CO2	AT-CO2-0	PERCENT	9.29	9.47	9.46	9.40	9.26	9.33	9.30	9.33	9.27	9.34	13.64	13.70	12.10	9.44	9.43	9.43
	FURNACE CO	AT-CO-0	PPM	12.45	13.65	12.21	13.50	11.88	11.87	11.82	11.72	11.80	11.95	65.90	81.37	123.34	14.83	11.78	11.88
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.01	59.90	60.27	0.00	0.00	0.00
	FLUE GAS (V)	FY-15	SCFM	115.4	115.2	115.3	115.8	115.8	115.6	115.2	115.7	116.6	115.9	116.8	117.5	116.8	112.0	112.2	112.7
ABSORBER FILE				ABS054	ABS055	ABS056	ABS057	ABS058	ABS059	ABS060	ABS61&63	ABS064	ABS064	ABS065	ABS066	ABS067	ABS068	ABS068	ABS068
	INLET SO2	AT-SO2-1	PPM	2155	2207	2197	2336	2236	2261	2250	2264	2241	2237	2062	2117	2074	2201	2209	2229
	INLET NOX	AT-NOx-1	PPM	510	492	73	503	71	67	487	500	76	500	703	704	649	102	104	106
	INLET O2	AT-O2-1	PERCENT	4.74	4.67	4.74	4.79	4.87	4.92	4.91	5.01	5.19	5.17	4.89	4.40	4.45	4.61	4.56	4.61
	OUTLET SO2	AT-SO2-2	PPM	130	134	163	146	184	254	194	200	222	165	14	40	336	206	90	71
	OUTLET NOX	AT-NOx-2	PPM	26	23	59	42	69	67	50	24	73	22	19	647	623	97	100	103
	OUTLET O2	AT-O2-2	PERCENT	5.14	5.06	5.11	5.21	5.30	5.47	5.49	5.58	5.64	5.70	5.74	5.78	5.50	5.04	5.15	5.19
	NO SPIKE	FT-101	#/HR	0.16	0.16	0.00	0.12	0.00	0.00	0.11	0.12	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00
	SO2 SPIKE	FT-102	#/HR	1.46	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	0.28	0.28	0.27	1.52	1.52	1.52
	NH3 SPIKE	FT-103	#/HR	0.104	0.093	0.000	0.088	0.000	0.000	0.085	0.088	0.000	0.086	0.070	0.000	0.000	0.000	0.000	0.000
	BED DP	PDT-19	H2O	1.40	1.86	1.68	1.67	2.16	2.44	1.93	1.70	1.38	1.73	12.25	17.73	14.99	1.82	1.73	1.89
	FLUE GAS (M)	FY-17	#/HR	516.4	496.3	501.5	502.2	502.0	500.1	502.1	503.4	505.7	502.4	260.7	262.3	260.0	270.1	270.6	271.1
	INLET P	PT-17	-H2O	6.86	6.84	6.82	6.87	6.85	6.79	6.76	6.84	6.97	6.66	6.48	6.62	6.54	6.50	6.46	6.53
	SCREEN DP	PDT-21	H2O	0.76	0.71	0.71	0.81	1.06	1.14	0.67	0.62	0.67	0.64	7.17	14.19	12.29	0.93	1.12	1.28
	GAS INLET	TE-19	DEG F	748	747	746	746	747	745	746	745	745	747	782	745	749	747	747	747
	GAS OUTLET	TE-21	DEG F	671	667	667	667	661	659	667	664	661	664	615	601	596	596	609	615
	SORB IN	TE-300	DEG F	773	774	764	773	763	756	797	748	742	769	786	733	758	744	782	802
	SORB OUT	TE-301	DEG F	690	690	687	687	677	679	693	687	682	691	723	714	632	687	715	715
	SO2 REMOVAL	SO2REF	PERCENT	93.9	93.9	92.4	93.6	91.6	88.4	91.1	90.8	89.8	92.4	99.3	97.9	82.7	90.3	95.8	96.7
	NOX REMOVAL	NOXREF	PERCENT	94.8	95.2	19.9	91.3	0.7	12.0	89.6	95.1	0.2	95.4	97.1	0.5	0.0	1.9	0.1	0.9
	FLUE GAS (V)	FY-17	SCFM	110.7	107.0	107.6	107.7	107.7	107.3	107.7	107.9	108.4	107.7	58.9	56.2	58.7	57.9	58.0	58.1
REGENERATOR FILE				REG054	REG055	REG056	REG057	REG058	REG059	REG060	REG61&63	REG064	REG064	REG065	REG066	REG067	REG068	REG068	REG068
	QUICK REP O2	AT-O2-4A	PERCENT	0.02	0.06	0.01	0.01	0.00	0.01	0.41	0.02	0.01	0.82	0.04	0.00	0.00	0.00	0.10	0.32
	REGEN SO2	AT-SO2-4	PERCENT	42.13	26.66	50.14	41.92	22.62	61.29	13.56	16.36	46.96	43.16	22.00	0.71	17.86	12.42	30.04	33.86
	REGEN CH4	AT-CH4-4	PERCENT	11.47	12.02	0.15	11.74	0.00	0.00	2.06	0.03	16.06	8.19	0.00	23.19	0.00	0.00	0.00	0.00
	REGEN CO2	AT-CO2-4	PERCENT	41.46	23.81	45.14	39.20	0.00	0.00	0.00	0.00	33.19	38.92	22.41	10.44	0.00	0.00	0.00	0.00
	REGEN H2S	AT-H2S-4	PERCENT	0.06	0.05	0.06	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.03
	REGEN O2	AT-O2-4B	PERCENT	0.39	0.20	0.25	0.16	0.01	0.60	0.10	0.11	0.10	0.16	0.03	0.00	0.09	0.00	0.20	0.34
	NATURAL GAS	FY-300	#/HR	0.60	0.60	0.30	0.60	0.88	0.88	0.88	0.88	0.60	0.60	0.28	0.28	0.41	0.44	0.88	1.33
	NITROGEN	FY-310	#/HR	0.00	1.05	0.00	0.00	2.10	0.00	4.20	4.20	0.00	0.00	1.00	1.00	1.90	2.10	2.10	2.10
	REGEN P	PT-300	H2O	0.56	3.50	0.34	6.60	8.04	1.56	50.76	14.92	0.58	1.83	1.75	-0.85	1.27	1.30	5.06	7.47
	SORB LEVEL	LT-300	INCHES	30.12	26.50	26.25	23.84	26.27	26.49	26.80	26.22	27.88	26.23	26.03	26.32	26.68	25.77	27.38	26.60
	TSORB (2")	TE-381	DEG F	846	841	842	848	1064	845	847	770	774	834	863	764	806	806	776	791
	TSORB (17")	TE-382	DEG F	896	860	865	849	1106	840	866	768	788	836	876	763	801	790	783	790
	TSORB (32")	TE-383	DEG F	836	846	846	864	814	763	817	721	807	868	861	745	737	780	748	756
	TSORB (47")	TE-384	DEG F	846	905	851	860	847	832	852	769	819	861	876	747	800	763	777	787
	TGAS(EXIT)	TE-385	DEG F	919	931	894	927	849	907	811	890	870	963	975	790	750	881	882	897
	T OFFGAS	TE-386	DEG F	156	153	143	162	210	197	287	217	182	164	146	110	168	150	179	191
	T COND EX	TE-387	DEG F	89	76	94	73	79	94	56	65	76	72	70	70	81	72	63	61
	T INC EX	TE-200	DEG F	363	338	412	346	373	356	388	360	376	373	396	338	392	378	371	361
	INCIN O2	AT-O2-5	PERCENT	20.07	20.06	19.76	20.02	19.97	20.06	19.90	20.01	19.93	16.26	19.84	20.00	19.81	19.83	19.93	19.94
	INCIN SO2	AT-SO2-5	PPM	596	601	500	583	447	503	616	645	591	580	400	134	412	320	576	649
FLUID BED HEATER FILE				FBH054	FBH055	FBH056	FBH057	FBH058	FBH059	FBH060	FBH61&63	FBH064	FBH064	FBH065	FBH066	FBH067	FBH068	FBH068	FBH068
	TSORB(12")	TE-373	DEG F	976	999	960	1000	997	1007	1026	900	960	960	930	850	901	882	901	900
	NATURAL GAS	FY-55	#/HR	5.38	5.66	5.29	5.70	5.90	5.46	5.92	6.10	5.46	5.46	5.76	5.36	4.69	5.37	5.89	5.76
	AHTR AIR (M)	FY-30	#/HR	316.9	312.4	319.5	311.6	312.8	313.6	307.3	336.4	326.0	326.5	361.7	383.6	369.7	371.8	369.1	369.2
	FBH VEL	SY-30	FT/SEC	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.50	3.50	3.50	3.50	3.50	3.50
	FBH O2	AT-O2-3	PERCENT	15.60	15.30	15.77	15.27	15.20	15.32	15.06	16.38	15.91	14.53	16.24	16.84	17.10	16.75	16.42	16.38
	TAHTR OUT	TE-370	DEG F	1193	1246	1176	1247	1263	1236	1290	1077	1170	1170	1110	966	930	1018	1074	1061
	T PLENUM	TE-372	DEG F	680	690	684	702	706	687	722	624	656	656	643	591	613	616	617	617
	TSORB(24")	TE-374	DEG F	960	994	954	995	991	1002	1019	896	946	946	926	847	896	886	896	896
	TVENT	TE-375	DEG F	878	899	869	904	906	912	929	818	860	862	847	782	834	826	827	827
	THUM OUT	TE-376	DEG F	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	FBH PRES	PT-376	H2O	8.62	8.48	8.57	8.29	6.04	7.79	7.93	8.47	8.46	8.91	10.71	11.67	10.61	11.12	11.28	11.26
	BED DP	PDT-376	H2O	8.54	9.36	9.82	9.87	11.06	11.57	10.78	8.74	9.30	10.22	8.71	10.48	12.09	11.78	11.78	11.79
	PLENUM DP	PDT-377	H2O	9.62	9.58	9.60	9.71	9.86	9.68	9.56	10.03	9.72	9.85	10.84	11.50	10.69	11.37	11.61	11.29
	FBH NOX	AT-NOx-3	PPM	13.70	15.61	13.99	16.15	17.06	14.84	17.28	5.62	13.27	206.72	15.96	11.14	8.93	11.27	12.79	13.10
	FBH SO2	AT-SO2-3	PPM	0.00	0.00	5.95	20.37	7.54	30.67	41.83	0.00	0.29	26.87	0.00	0.00	0.00	0.00	0.00	0.00
	AHTR AIR (V)	FY-30	SCFM	69.5	68.5	70.0	68.3	68.8	68.7	67.4	73.7	71.2	71.3	79.3	84.1	81.0	81.4	80.9	80.9
	REG NGAS (V)	FY-3006	SCFM	0.22	0.22	0.11	0.22	0.32	0.32	0.32	0.32	0.22	0.22	0.10	0.10	0.15	0.16	0.32	0.49
	REG N2 (V)	FY-3106	SCFM	0.00	0.24	0.00	0.00	0.48	0.00	0.96	0.96	0.00	0.00	0.23	0.23	0.43	0.48	0.48	0.48
FLUID BED COOLER FILE				FBC054	FBC055	FBC056	FBC057	FBC058	FBC059	FBC060	FBC61&63	FBC064	FBC064	FBC065	FBC066	FBC067	FBC068	FBC068	FBC068
	FBC AIR VEL	SY-360	FT/SEC	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.03
	AIR (M)	FY-360	#/HR	179.7	180.5	182.4	179.2	179.7	181.0	177.8	182.4	186.2	181.3	187.7	190.3	184.0	186.2	182.6	181.5
	T PLENUM	TE-362	DEG F	1000	1010	1010	1010	975	1000	1000	975	1000	1005	1005	1036	1035	1035	1035	999
	T LOWER	TE-363	DEG F	961	950	926	958	964	958	975	937	912	952	903	882	929	910	938	965
	BED DP	PDT-365	H2O	12.61	11.49	12.69	10.74	11.36	11.46	11.57	11.17	11.78	10.06	13.81	13.29	12.62	12.20	10.16	8.10
	PLENUM DP	PDT-367	H2O	6.00	6.40	6.36	6.15	6.44	6.22	6.28	6.46	6.40	6.50	6.54	6.96	6.42	6.09	6.72	6.46
	FBC PRES	PT-366	H2O	1.73	1.72	1.80	1.80	1.71	1.98	1.70	1.92	1.92	1.75	1.84	1.98	1.96	1.84	1.82	1.84
	T UPPER	TE-364	DEG F	962	961	929	959	966	958	976	939	913	964	904	884	929	911	940	966
	T HEATER	TE-361	DEG F	549	549	555	553	531	549	547	536	540	547	542	559	563	563	568	541
	T AIR	TE-360	DEG F	120	106	115	100	114	114	118	115	102	106	96	87	104	95	94	90
	AIR PRES	PT-360	PSIG	2.55	2.62	2.57	2.66	2.60	2.57	2.57	2.58	2.68	2.64	2.69	2.77	2.62	2.71	2.74	2.76
	AIR DP	FT-360	H2O	0.46	0.45	0.47	0.44	0.45	0.46	0.45	0.47	0.47	0.45	0.48	0.48	0.46	0.46	0.45	0.44
	INLET SO2(ADJ)	SO2REF	PPM	2307	2351	2361	2523	2418	2448	2433	2464	2469	2460	2201	2223	2184	2319	2342	2367
	OUTLET SO2(ADJ)	SO2REF	PPM	143	147	179	161	204	286	217	226	252	186	16	46	378	223	98	78
	INLET NOX(ADJ)	NOXREF	PPM	546	525	78	540	77	73	530	545	82	549	743	739	683	106	110	115
	OUTLET NOX(ADJ)	NOXREF	PPM	28	25	65	47	76	64	56	27	83	25	22	740	700	106	110	113
	AIR (V)	FY-360	SCFM	39.4	39.6	40.0	39.3	39.2	39.7	39.0	40.0	40.8	39.7	41.1	41.7	40.3	40.8	40.0	39.8
TEMPERATURE FILE				TEMP041	TEMP042	TEMP043	TEMP044	TEMP045	TEMP046	TEMP047	TEMP048	TEMP049	TEMP049	TEMP050	TEMP051	TEMP052	TEMP053	TEMP053	TEMP053
	COMB AIR T	TE-1	DEG F	127	113	118	103	119	122	126	120	104	112	100	91	110	101	101	96
	CO AIR HTR T	TE-3	DEG F	500	500	500	500	500	500	500	500	500	500	526	526	526	500	500	500
	MOT AIR T	TE-6	DEG F	86	80	90	73	83	86	87	83	78	78	73	64	84	73	68	63
	FUR REFR T	TE-4	DEG F	1615	1609	1605	1604	1600	1600	1602	1593	1617	1617	1847	1869	1843	1774	1778	1776
	FURN EXIT T	TE-9	DEG F	1151	1148	1160	1151	1155	1150	1151	1150	1157	1162	1246	1301	1373	1454	1449	1444
	TOT FGAS T	TE-15	DEG F	847	850	848	852	849	847	850	847	848	854	911	904	914	904	906	906
	ABS FGAS T	TE-18	DEG F	751	750	750	751	750	749	751	749	749	750	754	746	752	749	750	750
	HUM EXIT T	TE-27	DEG F	384	385	385	385	385	385	385	385	385	385	385	386	385	385	385	385
	BGHS TOP T	TE-29	DEG F	360	359	360	358	359	358	358	357	357	357	348	348	381	347	347	346
	BGHS BOT T	TE-30	DEG F	364	361	364	362	362	361	362	362	362	361	340	308	311	310	308	307
	ABS Z1 T	TIC-85	DEG F	750	750	750	750	750	750	750	750	750	750	751	751	750	750	750	750
	ABS Z2 T	TIC-88	DEG F	750	750	750	750	750	750	750	750	751	750	749	750	749	750	750	750
	ABS Z3 T	TIC-91	DEG F	750	750	750	750	750	749	750	750	750	750	749	750	751	749	750	749
	ABS Z4 T	TIC-94	DEG F	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750	750	750	750	750	750	750	752	751	750	750	750	750
	CW SUP T	TE-42	DEG F	119	118	116	109	113	116	117	117	112	109	107	100	113	101	97	96
	CW FUR EX T	TE-43	DEG F	154	149	151	143	147	150	150	150	144	142	140	134	144	130	126	124
	CW FGC EX T	TE-44	DEG F	106	93	97	83	88	103	95	90	95	88	96	79	94	89	86	80
	NAT GAS T	TE-20	DEG F	91	80	90	74	84	89	88	86	78	80	76	68	86	75	71	66

Table 9. Detailed Information for Test MBCUO-5

MBCUO-06	PARAMETER	TAG	E/U	1	2	3	4	5	6	7
COMBUSTOR FILE				COMB056	COM67&58	COMB061	COMB062	COMB063	COMB064	COMB065
	COMB AIR	FY-1	#/HR	426.2	443.1	443.0	443.0	443.0	443.0	443.1
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NATURAL GAS	FY-20	#/HR	22.06	22.93	22.93	22.93	22.93	22.93	22.92
	COAL	WKT-25	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FEEDER WT	WT-25	LBS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	EXCESS AIR	SY-X	%XSA	14.62	14.81	14.81	14.82	14.83	14.80	14.83
	HEAT INPUT	BTU	BTU/HR	583612	588301	588240	588234	588207	588298	586184
	FLUE GAS (M)	FY-16	#/HR	523.4	518.7	521.2	523.1	526.9	523.7	518.8
	FURNACE O2	AT-O2-0	%	4.81	3.77	4.02	4.04	4.07	4.03	3.77
	FURNACE P	PT-5	H2O	-1.00	-1.02	-1.01	-1.01	-0.98	-1.00	-1.02
	COMB AIR P	PT-1	PSIG	4.49	4.36	4.30	4.18	4.64	4.36	4.49
	MOTIVE AIR P	PT-3	PSIG	96.70	96.35	96.90	96.80	97.10	96.15	96.65
	NATURAL GAS P	PT-20	PSIG	4.14	4.15	4.16	4.12	4.15	4.11	4.12
	FLUE GAS P	PT-16	-H20	5.61	5.50	5.62	5.50	5.44	5.44	5.38
	COOL H2O P	PT-25	PSIG	116.90	116.58	116.63	117.06	115.93	116.74	116.70
	THEOR AIR	SY-X	#THEOAIR	371.62	385.89	385.84	385.84	385.63	385.89	385.81
	FURNACE CO2	AT-CO2-0	PERCENT	9.31	9.75	9.70	9.69	9.66	9.67	9.56
	FURNACE CO	AT-CO-0	PPM	13.01	12.90	10.99	10.96	11.30	11.04	12.87
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FLUE GAS (V)	FY-16	SCFM	112.3	111.3	111.8	112.2	112.8	112.3	111.2
ABSORBER FILE				ABS071	ABS072	ABS075	ABS076	ABS077	ABS078	ABS079
	INLET SO2	AT-SO2-1	PPM	2276	2290	2259	2245	2244	2296	341
	INLET NOX	AT-NOx-1	PPM	106	516	106	104	107	103	98
	INLET O2	AT-O2-1	PERCENT	4.94	4.15	4.24	4.34	4.48	4.38	4.42
	OUTLET SO2	AT-SO2-2	PPM	334	122	130	102	128	172	3
	OUTLET NOX	AT-NOx-2	PPM	106	18	107	101	103	98	101
	OUTLET O2	AT-O2-2	PERCENT	4.98	4.11	4.30	4.33	4.46	4.42	4.24
	NO SPIKE	FT-101	#/HR	0.00	0.10	0.00	0.00	0.00	0.00	0.00
	SO2 SPIKE	FT-102	#/HR	1.47	1.46	1.46	1.46	1.48	1.50	0.24
	NH3 SPIKE	FT-103	#/HR	0.000	0.126	0.000	0.000	0.000	0.000	0.000
	BED DP	PDT-19	H2O	1.60	2.02	2.48	2.87	3.60	3.93	4.13
	FLUE GAS (M)	FY-17	#/HR	496.6	506.7	510.4	510.8	513.9	512.3	505.7
	INLET P	PT-17	-H2O	7.22	7.06	7.21	7.07	7.10	7.07	6.98
	SCREEN DP	PDT-21	H2O	1.44	1.52	2.43	1.46	3.37	3.72	3.91
	GAS INLET	TE-18	DEG F	747	747	747	747	747	747	747
	GAS OUTLET	TE-21	DEG F	677	686	674	679	671	675	666
	SORB IN	TE-380	DEG F	736	776	763	773	752	763	755
	SORB OUT	TE-381	DEG F	689	696	664	694	690	694	680
	SO2 REMOVAL	SO2REF	PERCENT	85.3	94.7	94.2	95.6	94.3	92.5	99.2
	NOX REMOVAL	NOXREF	PERCENT	0.1	96.5	0.0	3.3	3.9	4.8	0.0
	FLUE GAS (V)	FY-17	SCFM	106.3	109.1	109.4	109.5	110.2	109.9	108.4
REGENERATOR FILE				REG071	REG072	REG075	REG076	REG077	REG078	REG079
	QUICK REP O2	AT-O2-4A	PERCENT	0.16	0.46	0.06	0.43	0.62	0.13	19.68
	REGEN SO2	AT-SO2-4	PERCENT	22.16	21.15	51.09	45.85	44.35	47.36	17.69
	REGEN CH4	AT-CH4-4	PERCENT	0.61	0.10	5.86	3.66	0.77	0.64	0.04
	REGEN CO2	AT-CO2-4	PERCENT	0.01	0.00	43.35	44.66	0.00	0.00	0.02
	REGEN H2S	AT-H2S-4	PERCENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.13	0.49	0.26	0.36	0.26	0.07	0.43
	NATURAL GAS	FY-300	#/HR	0.44	0.87	0.80	0.80	1.33	1.77	0.86
	NITROGEN	FY-310	#/HR	1.16	1.15	0.00	0.00	1.22	1.10	0.66
	REGEN P	PT-380	H2O	-1.00	0.31	5.67	5.59	4.82	4.19	-0.96
	SORB LEVEL	LT-380	INCHES	14.34	15.64	27.59	36.11	36.02	36.56	36.78
	TSORB (2")	TE-381	DEG F	706	721	840	866	870	855	751
	TSORB (17")	TE-382	DEG F	703	717	843	861	875	860	749
	TSORB (32")	TE-383	DEG F	664	676	842	832	806	785	716
	TSORB (47")	TE-384	DEG F	667	669	871	863	844	837	753
	TGAS(EXIT)	TE-385	DEG F	687	687	861	877	853	843	752
	T OFFGAS	TE-386	DEG F	248	254	246	249	247	249	244
	T COND EX	TE-387	DEG F	81	78	74	79	78	84	82
	T INC EX	TE-200	DEG F	445	437	488	494	463	486	487
	INCIN O2	AT-O2-5	PERCENT	19.74	19.67	19.35	18.63	18.72	18.37	19.02
	INCIN SO2	AT-SO2-5	PPM	314	344	587	596	711	726	208
FLUID BED HEATER FILE				FBH071	FBH072	FBH075	FBH076	FBH077	FBH078	FBH079
	TSORB(12")	TE-373	DEG F	745	745	1062	1061	969	969	826
	NATURAL GAS	FY-55	#/HR	4.79	4.30	5.96	6.57	5.90	5.80	4.82
	AHTR AIR (M)	FY-30	#/HR	418.1	356.1	280.1	330.3	321.0	317.2	349.6
	FBH VEL	SY-30	FT/SEC	3.50	3.00	3.00	3.50	3.19	3.20	3.18
	FBH O2	AT-O2-3	PERCENT	16.89	16.74	20.01	15.01	15.61	15.37	16.77
	TAHTR OUT	TE-370	DEG F	791	875	1364	1345	1233	1237	962
	T PLENUM	TE-372	DEG F	487	490	737	746	667	648	568
	TSORB(24")	TE-374	DEG F	741	740	1067	1047	965	964	822
	TVENT	TE-375	DEG F	691	680	941	923	850	859	731
	THUM OUT	TE-376	DEG F	500	500	500	500	500	500	500
	FBH PRES	PT-376	H2O	17.36	13.45	12.18	14.97	13.54	13.30	15.11
	BED DP	PDT-376	H2O	12.84	12.79	9.85	8.31	11.01	10.41	7.72
	PLENUM DP	PDT-377	H2O	11.93	9.73	8.71	10.49	9.97	9.82	9.92
	FBH NOX	AT-NOx-3	PPM	10.30	0.33	1.04	22.07	18.43	18.20	12.28
	FBH SO2	AT-SO2-3	PPM	0.00	0.00	3.72	14.65	0.00	0.28	0.96
	AHTR AIR (V)	FY-30	SCFM	91.64	78.06	61.39	72.38	70.37	69.63	76.63
	REG NGAS (V)	FY-3006	SCFM	0.16	0.32	0.22	0.22	0.49	0.65	0.32
	REG N2 (V)	FY-3106	SCFM	0.26	0.26	0.00	0.00	0.28	0.25	0.16
FLUID BED COOLER FILE				FBC071	FBC072	FBC075	FBC076	FBC077	FBC078	FBC079
	FBC AIR VEL	SY-360	FT/SEC	3.31	3.00	3.00	3.00	3.00	3.00	3.00
	AIR (M)	FY-360	#/HR	209.1	182.7	179.7	182.9	185.1	182.7	185.1
	T PLENUM	TE-362	DEG F	975	955	1006	950	875	875	875
	T LOWER	TE-363	DEG F	887	931	957	933	920	923	896
	BED DP	PDT-365	H2O	16.81	11.19	11.60	9.78	13.56	11.64	10.06
	PLENUM DP	PDT-367	H2O	7.24	6.66	6.34	6.49	6.47	6.47	6.24
	FBC PRES	PT-366	H2O	2.25	1.83	1.72	1.84	1.95	1.86	1.96
	T UPPER	TE-364	DEG F	886	933	968	935	920	925	896
	T HEATER	TE-361	DEG F	544	536	573	534	479	481	480
	T AIR	TE-360	DEG F	87	92	92	107	83	93	87
	AIR PRES	PT-360	PSIG	2.83	2.76	2.77	2.87	2.86	2.75	2.78
	AIR DP	FT-360	H2O	0.57	0.45	0.43	0.46	0.46	0.48	0.46
	INLET SO2(ADJ)	SO2REF	PPM	2466	2386	2346	2345	2364	2404	358
	OUTLET SO2(ADJ)	SO2REF	PPM	362	125	136	106	135	180	3
	INLET NOX(ADJ)	NOXREF	PPM	117	533	110	109	113	108	103
	OUTLET NOX(ADJ)	NOXREF	PPM	117	18	112	106	109	103	104
	AIR (V)	FY-360	SCFM	45.8	40.1	39.4	40.1	40.6	40.0	40.6
TEMPERATURE FILE				TEMP056	TEM67&58	TEMP061	TEMP062	TEMP063	TEMP064	TEMP065
	COMB AIR T	TE-1	DEG F	91	96	95	115	87	97	91
	CO AIR HTR T	TE-3	DEG F	550	400	400	400	400	400	400
	MOT AIR T	TE-6	DEG F	64	60	68	77	57	69	69
	FUR REFR T	TE-4	DEG F	1717	1736	1780	1791	1789	1792	1807
	FURN EXIT T	TE-9	DEG F	1386	1361	1354	1350	1337	1344	1338
	TOT FGAS T	TE-15	DEG F	856	856	853	851	854	852	853
	ABS FGAS T	TE-18	DEG F	750	750	750	750	750	750	750
	HUM EXIT T	TE-27	DEG F	383	386	383	377	375	364	351
	BGHS TOP T	TE-29	DEG F	353	354	354	350	347	335	328
	BGHS BOT T	TE-30	DEG F	353	356	356	350	349	334	328
	ABS Z1 T	TIC-85	DEG F	750	750	750	750	750	750	750
	ABS Z2 T	TIC-88	DEG F	750	750	750	750	750	750	750
	ABS Z3 T	TIC-91	DEG F	750	750	750	750	750	750	750
	ABS Z4 T	TIC-94	DEG F	750	750	750	750	750	750	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750	750	750	750
	CW SUP T	TE-42	DEG F	114	119	115	121	115	119	101
	CW FUR EXT	TE-43	DEG F	135	141	137	143	137	141	126
	CW FGC EXT	TE-44	DEG F	92	88	102	101	92	99	94
	NAT GAS T	TE-20	DEG F	73	69	75	83	66	77	74

Table 10. Detailed Information for Test MBCUO-6

MbCuO-07 Test Conditions

	11:00	04:30	01:45	04:45
Test Condition	1	4	5	6
Coal flow,lb/h	—	Y	Y	Y
Natural Gas flow,lb/h				
ABSORBER (1 ft x 8 ft)	12/5	12/7	12/8	12/9
Absorber temp control	750	750	750	750
TE18, F (gas inlet)	745	749	746	747
TE390,F (sorbent inlet)	745	735	760	730
Flue gas, acfm	107	56	108	110
, lb/hr	500	260	505	510
Sorbent flow,#/m	0.75	0.75	0.75	0.75
Inlet SO2,ppm	2300	2120	2070	2060
Outlet SO2,ppm	155	23	155	140
SO2 removal eff (exp), %	93	99	92	93
SO_2 removal eff (model), %				
Inlet NOx,ppm	505	610	580	530
Outlet NOx,ppm	51	605	580	500
NOx removal, %	90	—	—	—
SO2 flow,lb/hr	1.47	0.286	0.080	0.125
NO flow,lb/hr	0.10	—	—	—
NH3 flow,lb/h	0.116	—	—	—
REGENERATOR				
Regenerator temp control	850	850	850	850
TE381, F	834	867	840	828
TE382, F	834	872	835	847
TE383, F	811	856	855	925
TE384, F	842	905	910	920
TE385, F	935	935	937	940
Resi.time, min	120	90	90	60
NG flow, lb/h	0.60	0.30	0.60	0.60
H2 flow, lb/h	—	—	—	—
N2 flow, lb/h	—	1.0	—	—
NG&H2/(total S), Mol ratio	1	1	1	1
Equivalence Ratio (Phi=1 for NG/S=0.5, H2/S=2)	2	2	2	2
SO_2, %	45	21	42	46
CO_2, %	39	24	37	33
CH_4, %	14	1	20	23
Total, %	98	46	99	102
FLUID-BED HEATER				
TE373, F (12")	985	980	980	975
TE374, F (24")	980	980	980	970
SO2, ppm	—	—	10	18
WATER				
Start time	06:46	02:39	01:02	02:39
Start Bagmeter (Ft3)	381.3	520.0	306.4	964.5
Stop time	10:00	04:41	02:39	04:39
Stop Bagmeter (Ft3)	466.2	579.7	346.9	1014.1
Interval time (min)	194	122	97	120
Interval bagmeter (Ft3)	84.9	59.7	40.5	49.6
Collected H2O (g)	755.8	321.0	149.9	394.7
Water, lb/min	0.00859	0.00580	0.00341	0.00725
Drymeter flow, scfm	0.438	0.489	0.418	0.413
SULFUR ABSORBED, Mol/hr	0.0302	0.0169	0.0295	0.0303
SULFUR REGENERATED, Mol/hr	0.0311	0.0162	0.0277	0.0300
SULFUR BALANCE, %	+3.0	-4.1	-6.1	-1.0

Table 11. Daily Hand Data Sheet for Test MBCUO-7

SULFUR IN WT% IN SORBENT SAMPLES

TEST No.	ABSORBER inlet cone	1 top absorber	2	3	4	5	6 bottom absorber	outlet cone	REGENERATOR R1 bottom port	R2	R3	R4 top port
MBCUO-01 (1)	0.84			1.4	3.4			1.2	1.2	1.0	NA	
MBCUO-01 (2)	1.1			2.0	1.4			0.69	1.3	1.9	1.9	
MBCUO-01 (4)									1.5			
MBCUO-01 (5)	1.1			4.2				1.25	1.4			
Samples taken during regenerator sorbent flow pattern study:												
sorbent from regenerator cone bottom (black color)									1.7			
sorbent from regenerator cone bottom (metallic copper color)									0.8			
MBCUO-2 (2A)	0.86	0.86	0.86	0.89	0.89	0.86	0.92	1.4	0.98	1.12		1.6
MBCUO-2 (1)	0.87	0.91	0.89	0.88	0.88	0.88	0.86	1.32	0.88	1.15		
MBCUO-3 (1)	1.85	0.91	0.85	1.36	1.45	1.25	1.72	1.75	0.84	1.27	2.11	2.48
MBCUO-3 (2)	1.18	0.86			1.81		1.88	2.40	0.91	2.08	2.06	2.6
MBCUO-3 (3)	1.68	0.88				2.14	1.30	1.56	1.3	1.32	1.78	2.4
MBCUO-3 (4)	1.13	0.89					3.31		1.29	1.76	2.27	2.31
MBCUO-3 (5)	1.01	1.39					4.35		1.01	1.69	2.26	3.18
MBCUO-3 (6)	1.02	1.2					4.6	2.72	0.94	1.32	2.6	NA
MBCUO-3 (7)	1.04		1.72		3.66	3.60	4.9	2.54	1.08	1.7	1.92	?
MBCUO-4 (1)	0.9	1.02		1.01			1.06	1.9	0.74	1.15	2.44	
MBCUO-4 (2)	0.91	0.91		1.27			1.5	2.76	1.05	1.98	2.61	
MBCUO-4 (3)	1.15	0.99	1.05	1.13	1.25	1.6	2.14	2.83	2.43	2.63	2.97	
MBCUO-4 (4)	0.93	1.1	1.12	1.09	1.67	1.58	1.45	2.37	0.95	1.66		
MBCUO-4 (6)	0.87	0.84	0.93	1.06	1.42	2.76	1.66	2.67	0.60	0.53		
MBCUO-4 (7)	1.02	0.84	0.98	0.84	1.37	X	1.34	2.11	1.30			
MBCUO-4 (8)	1.84	1.09	1.16	1.14	1.17	1.19	2.10	2.56	1.47			
MBCUO-4 (9) H_2	1.14	1.11	1.09	1.22	1.41	1.07	1.49	2.60	1.38			

Table 12. Sulfur Analytical Results

MBCUO-5	(1)	1.20	1.22	1.22	1.28	1.36	1.26	2.36	2.83	1.13	2.01	3.27
MBCUO-5	(2)	1.07	1.08	1.08	1.08	1.08	1.66	1.09	1.32	1.01	2.12	
MBCUO-5	(3)									2.98	3.45	
MBCUO-5	(4)											
MBCUO-5	(5) H_2									1.69	3.60	
MBCUO-5	(5A)H_2	2.01		2.00		2.19	4.17	3.99	3.33	3.89	3.82	
MBCUO-5	(5B)H_2	1.85	1.90	1.96	1.93	1.99	2.00	2.81	3.48	3.63	3.69	
MBCUO-5	(7) H_2	1.68							2.45	2.60	4.03	X
MBCUO-5	(1A)									2.32	3.37	
MBCUO-5	(1B)	0.73							2.66	2.58	2.64	
MBCUO-5	(9A)	1.35							3.21	2.55	2.61	

....

<u>regn temp=700F, residence time = 60 min</u>

MBCUO-6	(1) H_2	3.74	4.24	4.03	4.02	3.86	4.45	4.51	4.96	5.04

MBCUO-6 (1) (regn inlet hopper = 5.03% S)
MBCUO-6 (1) (regn outlet hopper = 4.41% S)
MBCUO-6 (1) (absorber outlet hopper = 5.08% S)

<u>regn temp=700F, residence time = 60 min</u>

MBCUO-6	(2) H_2	4.23	4.72	4.77	5.02	4.85	4.38	5.5	6.375

MBCUO-6 (2) (regn outlet hopper = 5.14% S)

MBCUO-6 (2) (regn inlet hopper = 6.18% S)

MBCUO-6 (2) (absorber outlet hopper = 6.1% S)

MBCUO-6 (batch regn with H_2 after MBCUO-6-2, S=4.66%)
MBCUO-6 (regn condensate after batch regn, S=3.5%
condensate weight = 106 grams)

<u>regn temp=850F, residence time=120 min</u>

MBCUO-6 (9)NG 2.5 3.2
MBCUO-6 (9) (absorber inlet = 1.4% S)
MBCUO-6 (9) (regn inlet = 3.1% S)
MBCUO-6 (9) (regn outlet hopper = 1.5% S)
MBCUO-6 (9) (absorber outlet hopper = 3% S)

<u>regn temp=850F, residence time=120 min</u>

MBCUO-6 (10)NG 1.7 2.4
MBCUO-6 (10) (absorber inlet = 1.4% S)
MBCUO-6 (10) (regn outlet hopper = 1.2% S)
MBCUO-6 (10) (absorber outlet hopper = 2.4% S)

<u>regn temp=850F, residence time=120 min</u>

MBCUO-6 (11)H2 4.3 4.3 4.3
MBCUO-6 (11) (absorber inlet = 2% S)
MBCUO-6 (11) (regn outlet hopper = 2.6% S)
MBCUO-6 (11) (absorber outlet hopper = 3.5% S)

<u>regn temp=850F, residence time=120 min</u>

MBCUO-6 (13)H2 2.4 4.4 4.5
MBCUO-6 (13) (Absr inlet = 2.2% S)
MBCUO-6 (13) (regn outlet hopper = 1.9% S)
MBCUO-6 (13) (absorber outlet hopper = 3.9% S)

<u>regn temp=750F, residence time=120 min</u>

MBCUO-6 (14)H2 3.7 3.7 3.6
MBCUO-6 (14) (Absr inlet = 2.3% S)
MBCUO-6 (14) (regn outlet hopper = 2.6% S)
MBCUO-6 (14) (absorber outlethopper = 2.8% S)

MBCUO-4

ABSORBER DIFFERENTIAL PRESSURE PROFILES											
Times Top/Middle/Bottom			dP 1-4 "H_2O			dP 1-2 "H_2O			dP 3-4 "H_2O		
			top	mid	bot	top	mid	bot	top	mid	bot
7/18 12:20	12:15	12:10	3.2	3.2	3.2	0.1	0.2	0.2	1.0	1.0	1.8
7/19 06:30	06:40	06:50	4.0	3.9	4.0	0.1	0.1	0.2	2.3	1.0	1.6
7/20 03:35	03:30	03:26	4.2	4.3	4.3	0.2	0.2	0.2	1.7	1.2	1.4
7/22 01:37	01:36	01:33	5.2	5.3	5.2	0.2	0.2	0.2	1.4	1.4	1.6
7/23 12:55	12:33	12:23	6.0	6.0	6.0	0.2	0.2	0.2	2.1	1.9	1.6
7/24 20:49	21:00	21:05	4.4	4.5	4.4	0.4	0.4	0.4	0.6	0.9	1.7
7/25 10:00	10:05	10:20	4.8	4.8	4.8	0.1	0.2	0.3	0.6	0.8	1.3
7/26 14:15	14:10	14:40	4.0	4.0	4.1	0.1	0.2	0.2	0.7	1.3	1.8
7/27 11:36	11:10	11:00	3.6	3.4	3.4	0.2	0.2	0.2	1.8	1.2	1.5

MBCUO-5

TABLE IV. ABSORBER DIFFERENTIAL PRESSURE PROFILES											
Times Top/Middle/Bottom			dP 1-4 "H_2O			dP 1-2 "H_2O			dP 3-4 "H_2O		
8/16 08:26	08:29	08:33	1.6	1.6	1.6	0.0	0.0	0.1	0.7	0.6	0.5
8/17 7:27	7:29	7:31	1.9	1.9	1.9	0.0	0.0	0.1	0.8	0.5	0.5
8/18 11:10	11:12	11:00	2.2	2.2	2.2	0.0	0.0	0.1	1.1	1.6	1.5
8/21 10:23	10:26	10:30	1.7	1.7	1.7	0.0	0.0	0.1	0.6	0.6	0.6
8/22 13:45	13:51	13:53	1.8	1.8	1.8	0.0	0.0	0.0	0.6	0.6	0.6
8/23 06:20	06:21	06:22	13.0	13.1	13.3	6.5	3.0	5.2	1.5	.9	.4
8/24 06:55	06:56	06:57	18.5	18.9	18.6	2.5	2.2	1.5	15.0	7.0	6.7

MBCUO-6

ABSORBER DIFFERENTIAL PRESSURE PROFILES											
Times Top/Middle/Bottom			dP 1-4 "H_2O			dP 1-2 "H_2O			dP 3-4 "H_2O		
10/19 05:18	05:13	05:08	1.6	1.6	1.6	0.5	0.0	0.0	0.0	1.1	1.4
10/22 15:19	15:21	15:23	2.5	2.5	2.5	0.8	0.0	0.0	0.3	0.9	0.8
10/23 17:29	17:21	17:18	2.9	2.9	2.9	0.0	0.0	0.0	2.7	0.9	1.2
10/27 05:22	05:29	05:40	4.2	4.0	4.1	0.0	0.0	0.0	3.1	3.0	3.1

Table 13. Absorber Pressure Drop Measurements

Test	Sorbent	Sorbent attrited	# of hopper cycles	Hours of Operation	Attrition lb/hr	Attrition lb/hopper cycle	Inventory cycles accumulative
MBCUO-1							26.5
MBCUO-2	SOX-3	46.8 lb	2533	80	0.585	0.018	34.9
MBCUO-3	SOX-3	142.5 lb	6740	208	0.686	0.021	62.8
MBCUO-4	SOX-3	144.4 lb	4834	150.4	0.96	0.03	86.5
Different sorbent was used in the following test series.							
MBCUO-5	Grace	145. lb	6153	191.4	0.76	0.024	27.8
MBCUO-6	Grace	73. lb	5210	130.	0.56	0.014	52.9

Table 14. Sorbent Attrition Information

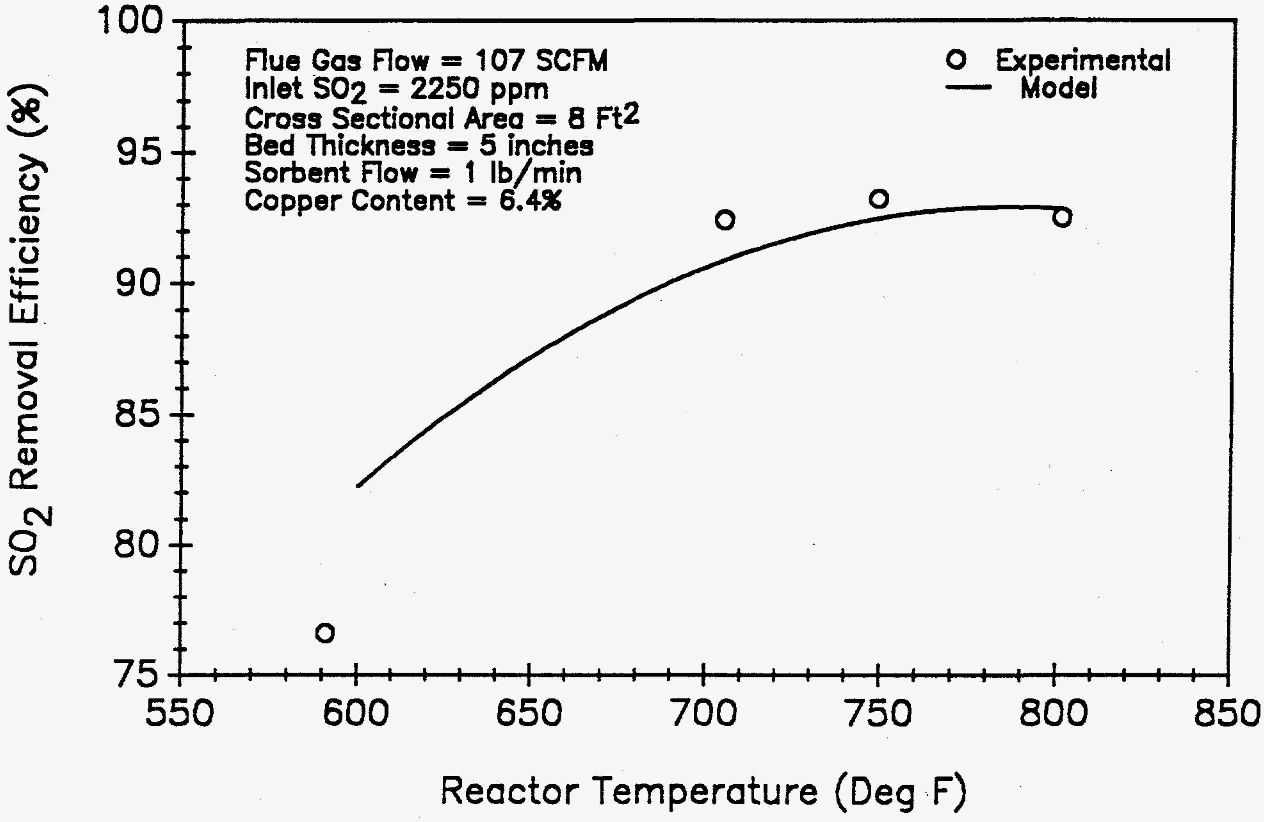

Figure 1. Effect of Temperature on SO_2 Removal: Experimental and Calculated

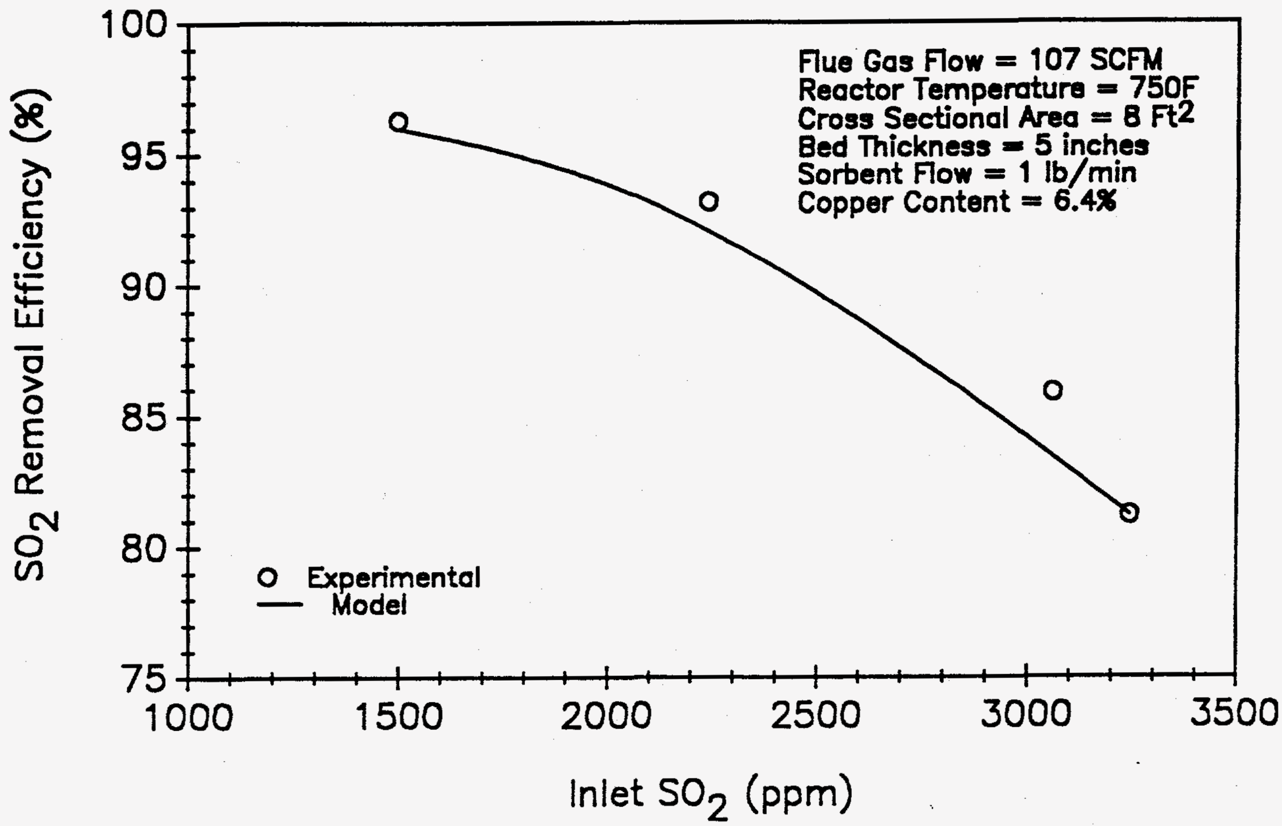

Figure 2. Effect of SO_2 Concentration on SO_2 Removal: Experimental and Calculated

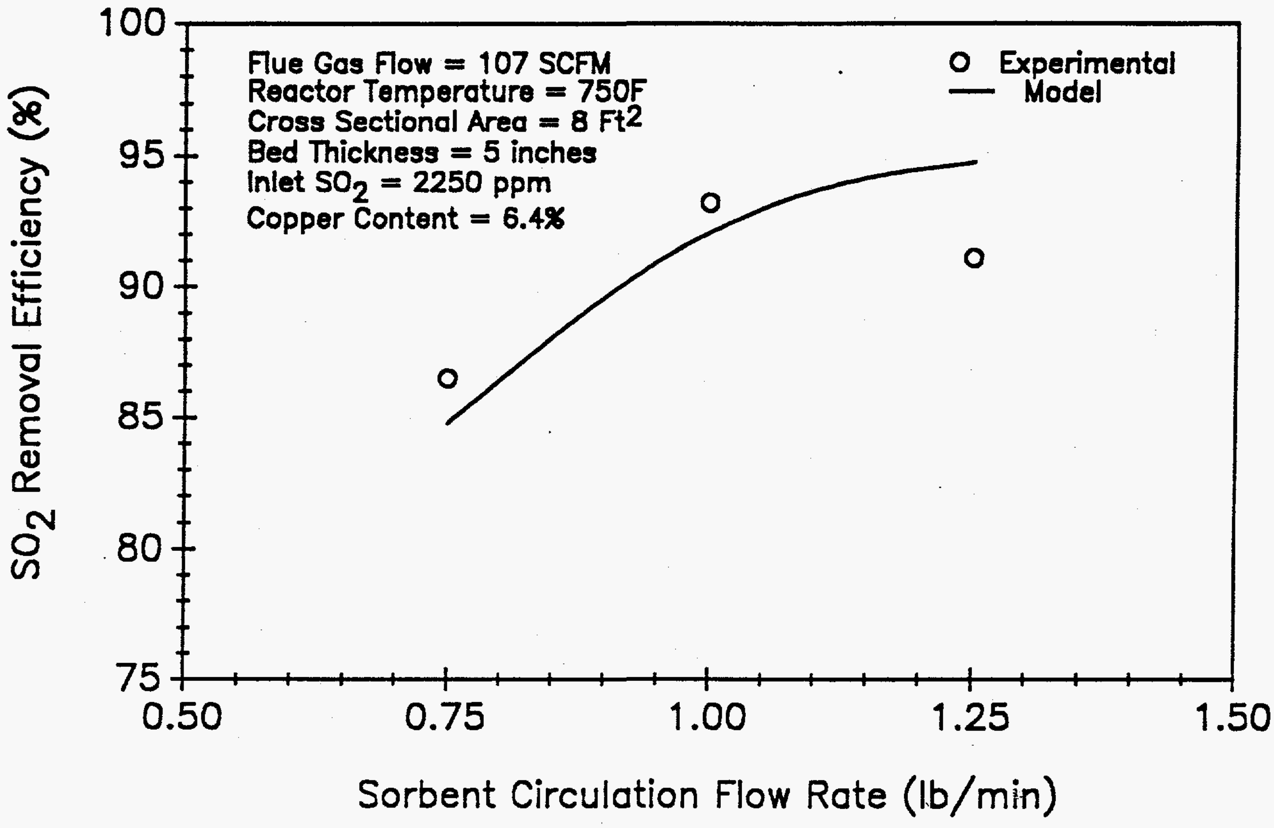

Figure 3. Effect of Sorbent Flow on SO_2 Removal: Experimental and Calculated

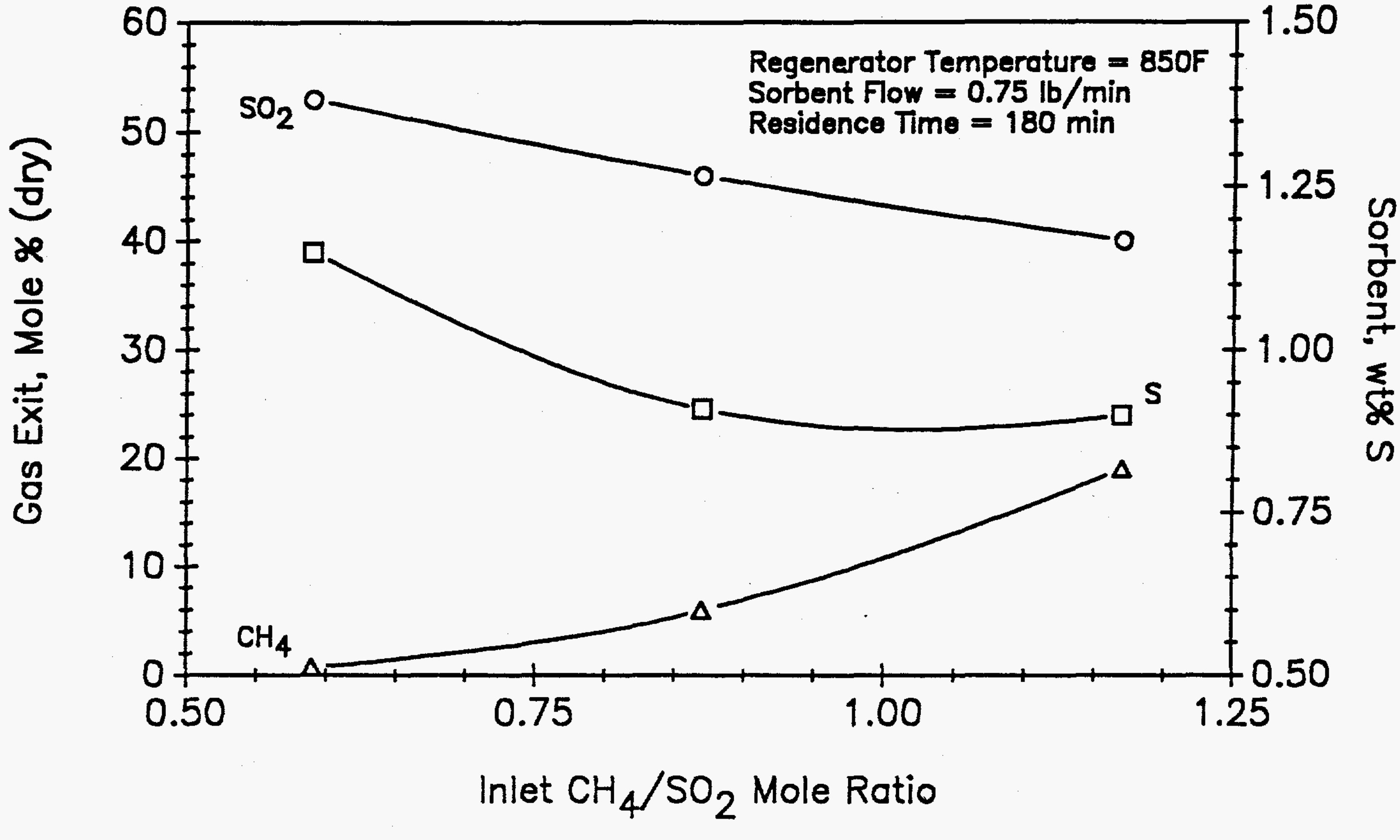

Figure 4. Effect of Regenerator Inlet Gas CH_4/S Molar Ratio on Regenerator Offgas Composition and Exit Sorbent Sulfur Content

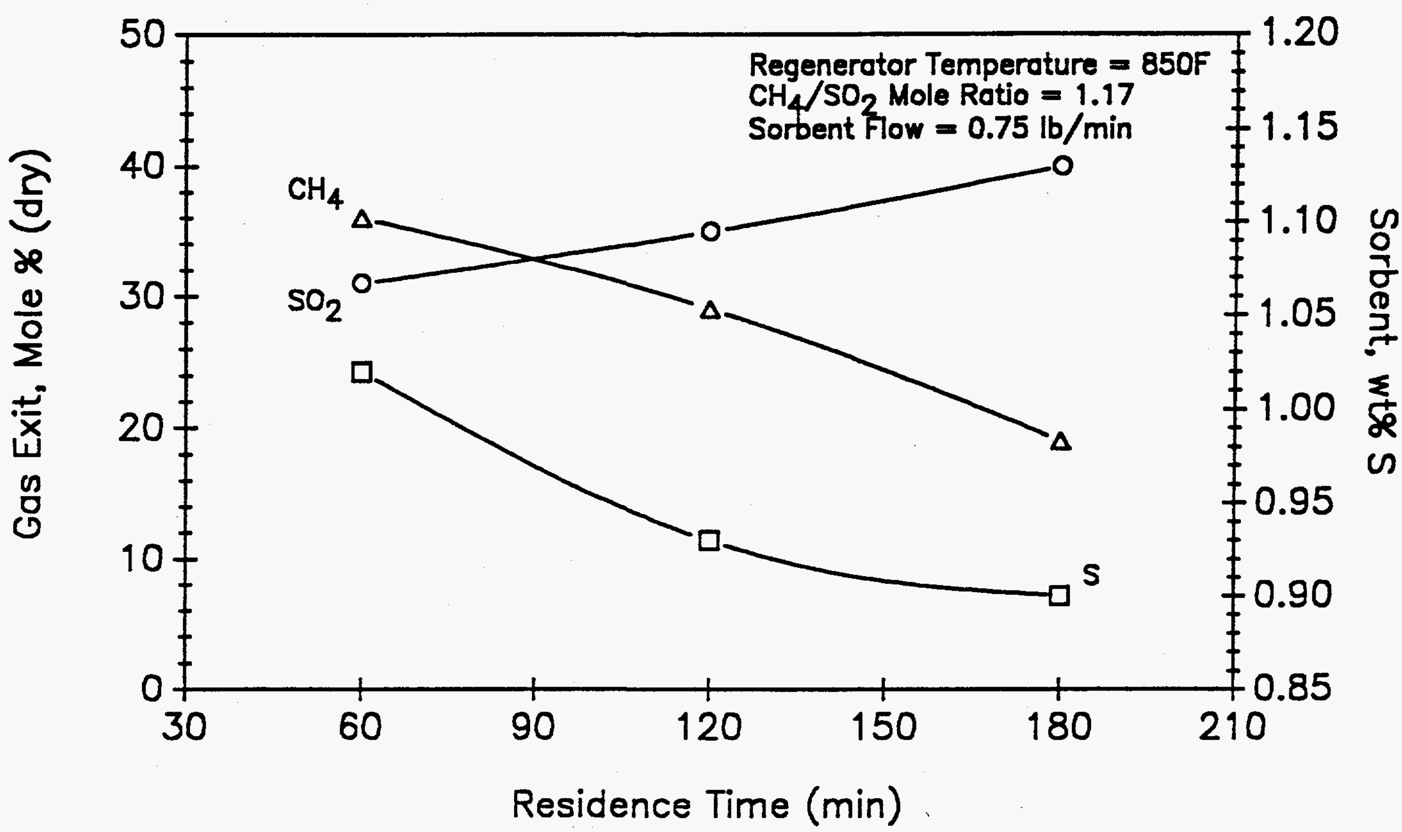

Figure 5. Effect of Regenerator Sorbent Residence Time on Regenerator Offgas Composition and Exit Sorbent Sulfur Content

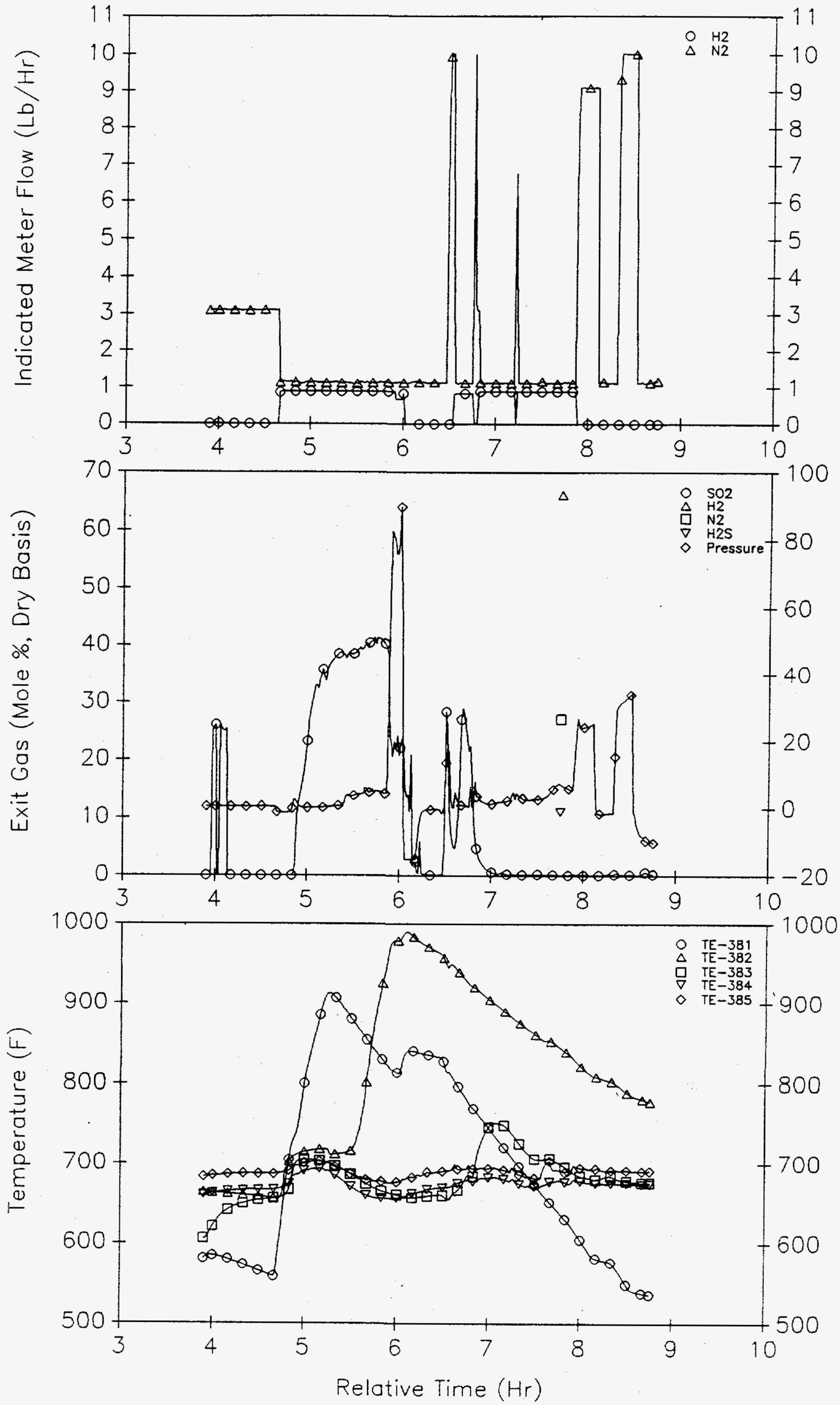

Figure 6. Batch Regeneration Results with Hydrogen

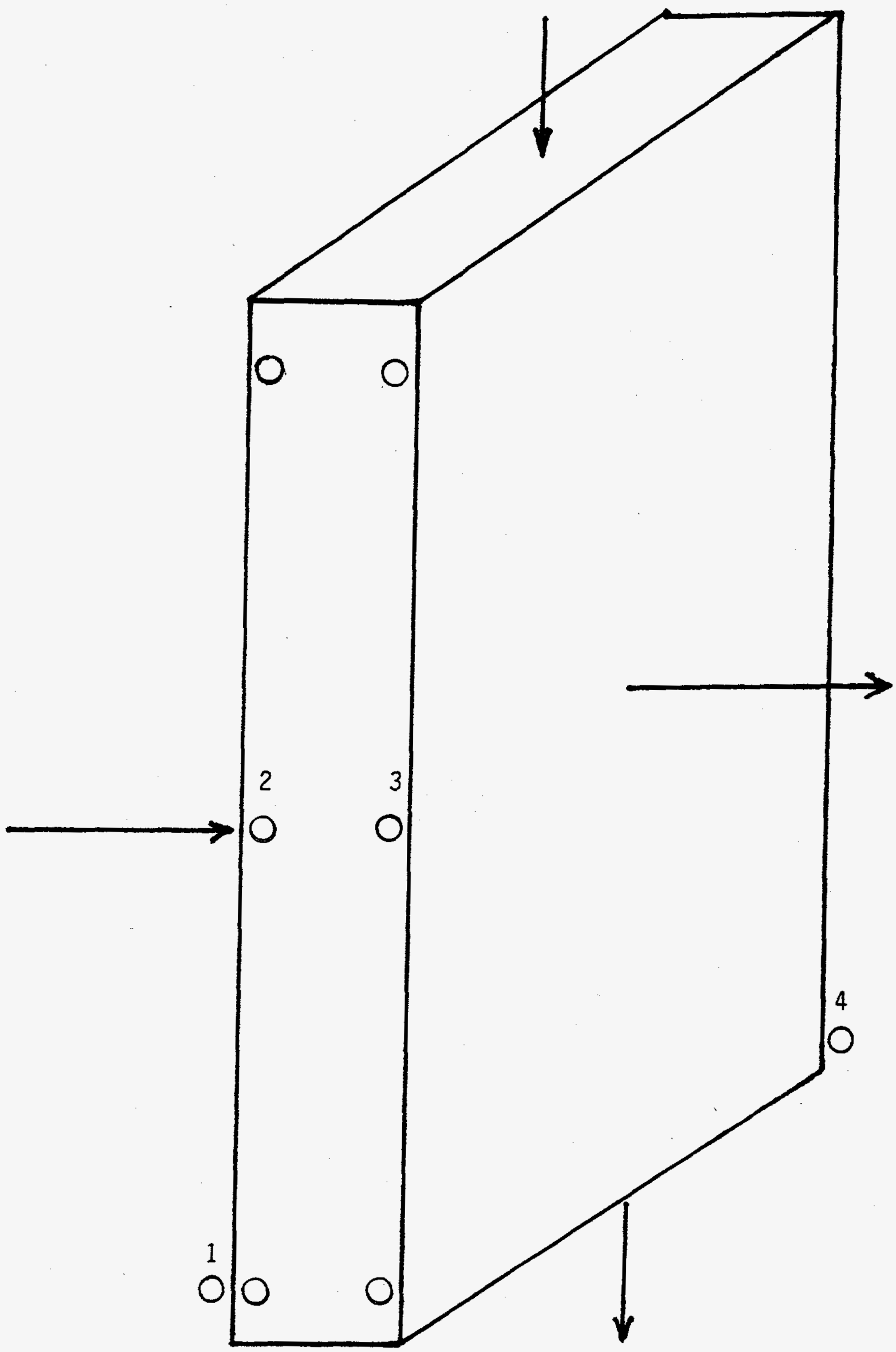

Figure 7. Location of Pressure Taps in the Absorber

PETC INTERIM REPORT II: January 1996
CRADA PC-95006

RESULTS OF LIFE-CYCLE TESTS UNDER COAL FIRING USING ABSORBER BAR SCREEN DESIGN

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Background

Favorable results of past investigations of the Moving-Bed Copper Oxide (MBCuO) process while burning coal were not obtained in the Life-Cycle Test System (LCTS). System performance in the absorber would degrade as ash and/or sorbent fines accumulated on the sorbent retention screens. Removal of SO_2 in the absorber typically decreased while pressure drop through the absorber increased. This degradation continued to occur despite changes made in process variables to enhance system performance (such as decreasing the spike level of SO_2 in the flue gas; increasing the sorbent circulation flow rate; decreasing the amount of flue gas passing through the absorber; increasing the pressure, frequency, and duration of back-pulsing the screens, etc.). Subsequent disassembly revealed that the absorber and bed was fouled with ash which was not purged from the vessel during LCTS operation.

The initial design of the retention screen incorporated a square wire mesh (316 SS, 35 mesh, 0.0176" square opening by 0.011" wire diameter) affixed by tack-welding to a perforated plate (316 SS, 0.125" thick, 1" diameter hole on a hexagonal pattern with 0.25" bar resulting in 1.25" center to center spacing). After consultation with the consortium partners, a new retention screen design using vertical bars fabricated by Hendrick Manufacturing Company was formulated. A schematic depicting the cross section of the bar screen is included in Figure 1. The retention screen consists of stainless steel vertical bars spaced slightly apart, resulting in vertical slots that retain particles of a certain diameter. The cross-sectional area of each bar is shaped like a "golf tee" so that any particle able to penetrate the minimum slot opening encounters a diverging nozzle arrangement and thus the particle is free to propagate through the rear of the screen. At the sorbent/screen interface, the bar measures 0.140" width and spaced 0.030" apart (i.e., the minimum slot opening). The bar is 0.375" thick with 0.0625" metal width at the screen exit. Of the total 0.375" metal thickness, 0.25" has the constant 0.0625" bar width; the last 0.125" thickness transitions from the 0.0625" metal width up to 0.140" metal width at the sorbent interface. From the perspective of a particle less than 0.030", the fragment slips through the minimum slot opening of 0.030", follows the slot that expands from 0.030" to 0.108" over 0.125" travel, and then follows a 0.25" travel-path over a constant maximum slot opening of 0.108".

A design change to the back-pulsor assembly was also incorporated. The original assembly consisted of eight chambers segmenting the cross-sectional area of the rear retention screen. Each chamber provided screen coverage of 6" bed width by 4' bed height. Two horizontal rows, each containing 4 chambers, provided total screen coverage of 2' bed width by 8' bed height. Each chamber contained one venturi nozzle to deliver the back-pulse. In an effort to minimize any flow disruption to the furnace, the chambers were sequenced to pulse such that only a quarter of the total bed area was back-pulsed at one time. An increase in back-pulsing capability was implemented by doubling the number of venturi in each chamber from one to two. Also, better sealing of the chamber to the rear screen was incorporated.

The purpose of the most recent test (MBCuO-07) was to characterize the effectiveness of the bar screens in handling ash and sorbent fines while burning coal in the LCTS. The LCTS was tested between December 4 and 9, 1995. Absorber bed dimensions were held constant at 8' height by 1' width by 5" bed depth, replicating nominal conditions identified during prior LCTS operation using natural gas fire. Due to depletion of the UOP sorbent inventory, Grace sorbent (0.0625" dia) was used for this testing. Four steady state test periods were attained (chronologically identified as conditions 1, 4, 5, and 6 respectively); a fifth period (condition 2) could not be sustained due to excessive pressure drop through the absorber and was abandoned. Condition 1 utilized natural gas fire; conditions 4-6 utilized a co-fire of coal (Illinois, Old Ben No. 24) with minimum natural gas support. Table 1 is a summary of test conditions and times.

RESULTS AND DISCUSSION

Tables 2 and 3 contain a summary of preliminary (hand-recorded daily) and formal (computer-averaged) results, respectively. Table 4 summarizes absorber differential pressure profiles obtained at various times during testing. For Table 4, the location of pressure taps are identified as follows: subscript "1-2" refers to pressure drop across the inlet screen, subscript "3-4" refers to pressure drop across the outlet screen, and subscript "1-4" refers to the total pressure drop collectively across the inlet screen, sorbent bed, and outlet screen. Several general observations and actions taken during the test are included in the following.

Table 5 lists ash removals from the LCTS. After firing with natural gas, sorbent particles/dust were removed from the inlet and outlet absorber ash pots. A weight of 17.1 pounds of mostly sorbent particles were discovered. The large amount of these particles and the reduced amount during later collections at these pots suggest that these were particles too large to fit through the previous screens, but small enough to fit through the bar screens. Thus, it was speculated that these particles had accumulated in the bed during previous testing with this sorbent.

As test periods with coal firing were conducted, the transport hopper required a longer fill time due to the deposition of ash in the absorber. Several instances of complete loss of sorbent flow in the absorber were observed. The pulsing of the absorber was effective in breaking up these blockages.

Figures 2-5 depict key LCTS process parameters versus time for all test conditions studied. Parameters for both the furnace and the absorber are emphasized to elucidate screen performance in the absorber.

Condition #1 (110 SCFM, no coal firing, no pulsing) was chosen to repeat a baseline performance condition previously investigated in the prior test (MBCuO-06-9). (See Figure 2 for further details of condition #1.) The SO_2 removal for condition #1 (93%) is in excellent agreement with the SO_2 removal from MBCuO-06-9 (94%), indicating that substitution of the new screens apparently did not influence the sulfation chemistry in the absorber. The pressure drop through the absorber (including front and rear sorbent retention screens and the sorbent bed) remained relatively constant at 1.4" H_2O. (See PDT-19 in Figure 2.) The pressure drop for MBCuO-06-9 was 2.5" H_2O, indicating that screen replacement was effective in lowering the pressure drop through the absorber.

Condition #2 was identical to condition #1 except that the furnace was fired on coal. In condition #2, (110 SCFM, coal firing, no pulsing) the differential pressure rapidly built up across the absorber (see Figure 3). Full flue gas flow (110 SCFM) through the absorber resulted in excessive ash accumulation. The SO_2 removal efficiency decreased with increasing pressure drop. Because the design limitation of pressure drop in the absorber was approached (20" H_2O), condition #2 was not sustainable and was therefore terminated. Between condition #2 and #4, scrubbing of the absorber (circulating sorbent without flue gas flow through the absorber) was effective in reducing the differential pressure.

For condition #4, half of the flue gas was flowed through the absorber. In condition #4, (55 SCFM, coal firing, no pulsing), the differential pressure across the absorber remained relatively constant at approximately 2" H_2O. This result implies that the ash entering the absorber through the inlet screen is balanced by the ash leaving the absorber through the transport hopper and the rear screen. Since the absorber was operated at "half load" (i.e., half flue gas flow), a very high SO_2 removal (99%) was demonstrated.

Condition #5 was identical to condition #2, except that the absorber was back-pulsed at regularly timed intervals. During condition #5 (continuous operation of the sorbent pulsers at 30 second intervals between pulses, coal firing, 110 SCFM), the differential pressure across the absorber remained relatively constant at 3 "H_2O (see Figure 4). SO_2 removal was demonstrated at approximately 93%, consistent with the SO_2 removal found in condition #1 (no coal). This result demonstrates the successful nature of the new screens: a repeatable SO_2 removal with sustainable low pressure drop (with continuous back-pulsing of the screen) was feasible under coal fire and total flue gas flow (110 SCFM) through the absorber.

To further investigate the effect of back-pulsing the absorber, condition #6 was identical to condition #5 except that the manner of pulsing was changed. Instead of a regularly timed pulse, the differential pressure was allowed to build up to a value (6" H_2O) and rapidly pulsed down until a lower threshold (3" H_2O) was attained. The pulsers would cease operation and the cycle of pressure growth was allowed to repeat. This method was also effective in reducing the differential pressure across the absorber (see Figure 5). An extremely brief period of rapid pulsing (1-2 minutes with typically two cycles of all eight chambers being pulsed) resulted in a quick return to the initial pressure drop (3" H_2O) identified in condition #5. The SO_2 removal (93%) was not greatly influenced by the pulsing and was consistent with prior test conditions. However, it appears that a slight decrease in SO_2 removal occurs as the bed pressure drop increases.

For both methods of pulsing the absorber, the SO_2 removal efficiency did not significantly differ from condition #1, where the flue gas contained no ash.

During conditions #5 and #6, no bypass flow was used around the absorber while burning coal to allow a quantification of the ash /sorbent dust distribution. Although no bypass of flow is desired, the pressure control valve does not provide complete closure and therefore a small amount of bypass flow can occur. Details of the ash removals are tabulated in Table 5. The results for these two test periods should be added together due to an apparent blockage in the fluid bed heater (FBH) baghouse during condition #5. When added together and ratioed, results for conditions #5 and #6 combined are as follows:

Furnace ashpot:	35.9%
Absorber inlet ashpot:	7.4%
Absorber outlet ashpot:	7.6%
Flue gas baghouse:	9.6%
FBH baghouse:	39.5%

Hence for the coal burned, one third of the ash remains in the furnace ash pit. The remaining two thirds of the ash is carried over to the absorber. Subtracting out the ash contribution remaining in the furnace ash pit, and normalizing the remaining ash amounts, the distribution of ash carried over from the furnace as fly ash (no distinction was made between fly ash and sorbent dust) is as follows:

Absorber inlet ashpot: 11.6%
Absorber outlet ashpot: 11.9%
Flue gas baghouse: 15.0%
FBH baghouse: 61.6%

Hence of the carried-over ash, 15% passes through the absorber and is deposited in the flue gas baghouse. The other 85% is captured by the absorber. Approximately two thirds of the fly ash is trapped in the sorbent bed, transported to the FBH, elutriated from the sorbent by the fluidizing gas, and lastly captured by the FBH baghouse.

Sorbent attrition was of the same order of magnitude as in previous tests. A total of 67.3 lbs of sorbent was lost to attrition in 6 days of testing. Although the bar screens passed larger sorbent particles, this appears to have little effect on the overall attrition rate of the sorbent. Details of the sorbent inventory, additions, removals, attrition, and sorbent transport data are found in Table 6.

TABLE 1. TEST CONDITION SUMMARY					
Test Condition	1	2	4	5	6
Start Day	12/4	12/6	12/6	12/7	12/8
Start Time	14:14	02:00	08:54	09:02	09:17
Finish Day	12/5	12/6	12/7	12/8	12/8
Finish Time	13:45	06:49	06:27	05:40	06:20
Furnace Fuel	NG	Coal	Coal	Coal	Coal
Abs.Flue Gas Flow (SCFM)	110	110	55	110	110
Absorber Temp (°F)	750	750	750	750	750
Absorber Inlet SO_2 conc. (ppm)	2250	2070	2070	2070	2070
Ammonia /NOx ?	Y	N	N	N	N
Sorbent Flow (lb/min)	0.75	0.75	0.75	0.75	0.75
Pulsing Type	None	None	None	Contin-uous	Inter-mittent
Reducing Gas	N.G.	N.G.	N.G.	N.G.	N.G.
Reg. Temp (°F)	850	850	850	850	850
Residence Time (min.)	120	90	90	90	60
Reducing Gas Flow (lb/hr)	0.6	0.6	0.3	0.6	0.6
Reg. N_2 Flow (lb/hr)	0	0	0	0	0
Reg. Vent N_2 Flow (lb/hr)	0	0	0	0	0
Reg N_2 flow to I'Lock?	N	N	N	N	N

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Table 2

MbCuO-07 Test Conditions

	11:00	04:30	01:45	04:45
Test Condition	1	4	5	6
Coal flow,lb/h	—	Y	Y	Y
Natural Gas flow,lb/h				
ABSORBER (1 ft x 8 ft)	12/5	12/7	12/8	12/9
Absorber temp control	750	750	750	750
TE18, F (gas inlet)	745	749	746	747
TE390,F (sorbent inlet)	745	735	760	730
Flue gas, scfm	107	56	108	110
, lb/hr	500	260	505	510
Sorbent flow,#/m	0.75	0.75	0.75	0.75
Inlet SO2,ppm	2300	2120	2070	2060
Outlet SO2,ppm	155	23	155	140
SO2 removal eff (exp), %	93	99	92	93
SO_2 removal eff (model), %				
Inlet NOx,ppm	505	610	580	530
Outlet NOx,ppm	51	605	580	500
NOx removal, %	90	—	—	—
SO2 flow,lb/hr	1.47	0.286	0.080	0.125
NO flow,lb/hr	0.10	—	—	—
NH3 flow,lb/h	0.116	—	—	—
REGENERATOR				
Regenerator temp control	850	850	850	850
TE381, F	834	867	840	828
TE382, F	834	872	835	847
TE383, F	811	856	855	925
TE384, F	842	905	910	920
TE385, F	935	935	937	940
Resi.time, min	120	90	90	60
NG flow, lb/h	0.60	0.30	0.60	0.60
H2 flow, lb/h	—	—	—	—
N2 flow, lb/h	—	1.0	—	—
NG&H2/(total S), Mol ratio	1	1	1	1
Equivalence Ratio (Phi=1 for NG/S=0.5, H2/S=2)	2	2	2	2
SO_2, %	45	21	42	46
CO_2, %	39	24	37	33
CH_4, %	14	1	20	23
Total, %	98	46	99	102
FLUID-BED HEATER				
TE373, F (12")	985	980	980	975
TE374, F (24")	980	980	980	970
SO2, ppm	—	—	10	18
WATER				
Start time	06:46	02:39	01:02	02:39
Start Bagmeter (Ft3)	381.3	520.0	306.4	964.5
Stop time	10:00	04:41	02:39	04:39
Stop Bagmeter (Ft3)	466.2	579.7	346.9	1014.1
Interval time (min)	194	122	97	120
Interval bagmeter (Ft3)	84.9	59.7	40.5	49.6
Collected H2O (g)	755.8	321.0	149.0	394.7
Water, lb/min	0.00659	0.00580	0.00341	0.00725
Drymeter flow, scfm	0.438	0.489	0.418	0.413
SULFUR ABSORBED, Mol/hr	0.0302	0.0169	0.0295	0.0303
SULFUR REGENERATED, Mol/hr	0.0311	0.0162	0.0277	0.0300
SULFUR BALANCE, %	+3.0	-4.1	-6.1	-1.0
[illegible] mole → =n	0.15	0.075	0.15	0.15
Air / Exit	0.0960	0.042	0.0756	0.108
% Balance	-36.0	-44.0	-49.6	-28.0
[illegible] mole C =n	0.0325	0.0188	0.0325	0.0325

PROTECTED CRADA INFORMATION

Table 3: Computer–Averaged LCTS Process Data for MBCuO–07.

MBCUO-07	PARAMETER	TAG	E.U.	1	2	3	4
COMBUSTOR FILE				COMB067	COMB068	COMB069	COM70671
	COMB AIR	FY-1	#/HR	463.1	482.1	482.1	482.1
	MOTIVE AIR	FY-3	#/HR	0.00	21.86	21.83	21.98
	NATURAL GAS	FY-20	#/HR	22.82	3.33	3.33	3.34
	COAL	WKT-28	#/HR	0.00	36.78	36.64	36.58
	FEEDER WT	WT-26	LBS	0.00	41.19	39.80	38.18
	EXCESS AIR	SY-X	%XSA	20.07	26.28	26.38	27.02
	HEAT INPUT	BTU	BTU/HR	566666	607812	604670	606226
	FLUE GAS (M)	FY-18	#/HR	526.4	561.3	566.3	567.0
	FURNACE O2	AT-O2-0	%	3.79	3.66	3.64	3.58
	FURNACE P	PT-5	H2O	-0.96	-1.01	-0.96	-0.98
	COMB AIR P	PT-1	PSIG	4.72	4.71	4.79	4.43
	MOTIVE AIR P	PT-3	PSIG	0.26	96.12	96.17	96.02
	NATURAL GAS P	PT-20	PSIG	4.17	4.88	4.86	4.88
	FLUE GAS P	PT-16	-H2O	5.29	6.29	6.01	6.06
	COOL H2O P	PT-36	PSIG	156.46	156.14	154.18	164.31
	THEOR AIR	SY-X	#THEOAIR	386.70	389.13	387.86	387.67
	FURNACE CO2	AT-CO2-0	PERCENT	9.80	14.68	14.79	14.86
	FURNACE CO	AT-CO-0	PPM	9.70	77.94	80.60	81.28
	MOTIVE AIR V	SY-3	FT/SEC	0.00	80.04	80.14	80.08
	FLUE GAS (V)	FY-18	SCFM	112.4	120.3	119.8	121.6
ABSORBER FILE				ABS081	ABS082	ABS083	ABS84486
	INLET SO2	AT-SO2-1	PPM	2166	2118	2080	2081
	INLET NOX	AT-NOx-1	PPM	606	618	587	626
	INLET O2	AT-O2-1	PERCENT	4.26	3.87	3.66	3.84
	OUTLET SO2	AT-SO2-2	PPM	146	23	164	143
	OUTLET NOX	AT-NOx-2	PPM	53	608	578	498
	OUTLET O2	AT-O2-2	PERCENT	4.30	4.03	3.79	4.08
	NO SPIKE	FT-101	#/HR	0.10	0.00	0.00	0.00
	SO2 SPIKE	FT-102	#/HR	1.48	0.28	0.08	0.13
	NH3 SPIKE	FT-103	#/HR	0.116	0.000	0.000	0.000
	BED DP	PDT-19	H2O	1.38	2.03	3.08	4.26
	FLUE GAS (M)	FY-17	#/HR	488.7	281.2	508.5	511.3
	INLET P	PT-17	-H2O	6.96	7.21	7.70	7.77
	SCREEN DP	PDT-21	H2O	3.86	1.23	0.81	1.48
	GAS INLET	TE-18	DEG F	746	748	747	747
	GAS OUTLET	TE-21	DEG F	584	641	677	678
	SORB IN	TE-380	DEG F	742	738	749	746
	SORB OUT	TE-381	DEG F	706	708	702	686
	SO2 REMOVAL	SO2REF	PERCENT	93.1	98.9	92.5	93.0
	NOX REMOVAL	NOXREF	PERCENT	89.5	0.9	0.5	3.8
	FLUE GAS (V)	FY-17	SCFM	108.9	58.8	108.0	108.8
REGENERATOR FILE				REG081	REG082	REG083	REG84486
	QUICK REP O2	AT-O2-4A	PERCENT	0.13	0.42	0.01	0.01
	REGEN SO2	AT-SO2-4	PERCENT	44.18	21.28	41.64	46.34
	REGEN CH4	AT-CH4-4	PERCENT	14.10	1.28	19.24	23.27
	REGEN CO2	AT-CO2-4	PERCENT	38.82	23.74	37.36	33.32
	REGEN H2S	AT-H2S-4	PERCENT	0.00	0.00	0.00	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.34	0.08	0.06	0.12
	NATURAL GAS	FY-300	#/HR	0.60	0.30	0.60	0.60
	NITROGEN	FY-310	#/HR	0.00	1.00	0.00	0.00
	REGEN P	PT-380	H2O	11.21	10.89	16.09	4.92
	SORB LEVEL	LT-380	INCHES	26.76	15.66	15.60	12.87
	TSORB (2")	TE-381	DEG F	837	868	840	528
	TSORB (17")	TE-382	DEG F	836	872	841	847
	TSORB (32")	TE-383	DEG F	811	868	864	926
	TSORB (47")	TE-384	DEG F	842	907	911	923
	TGAS(EXIT)	TE-385	DEG F	930	936	936	941
	T OFFGAS	TE-386	DEG F	261	260	256	251
	T COND EX	TE-387	DEG F	77	83	83	84
	T INC EX	TE-200	DEG F	800	616	828	512
	INCIN O2	AT-O2-5	PERCENT	16.86	18.66	18.64	18.37
	INCIN SO2	AT-SO2-5	PPM	502	479	706	624
FLUID BED HEATER FILE				FBH081	FBH082	FBH083	FBH84486
	TSORB(12")	TE-373	DEG F	986	986	983	978
	NATURAL GAS	FY-66	#/HR	6.26	5.70	5.67	5.70
	AHTR AIR (M)	FY-30	#/HR	274.7	313.7	316.8	316.6
	FBH VEL	SY-30	FT/SEC	2.81	3.20	3.20	3.20
	FBH O2	AT-O2-3	PERCENT	15.89	15.46	15.43	15.40
	TAHTR OUT	TE-370	DEG F	1236	1211	1202	1213
	T PLENUM	TE-372	DEG F	564	568	570	567
	TSORB(24")	TE-374	DEG F	982	982	979	972
	TVENT	TE-375	DEG F	568	581	580	588
	THUM OUT	TE-376	DEG F	501	498	500	500
	FBH PRES	PT-378	H2O	18.80	23.24	22.86	22.80
	BED DP	PDT-376	H2O	7.77	9.64	11.12	12.07
	PLENUM DP	PDT-377	H2O	8.09	9.18	9.43	9.44
	FBH NOX	AT-NOx-3	PPM	13.46	17.72	17.46	14.22
	FBH SO2	AT-SO2-3	PPM	0.96	0.00	14.96	16.98
	AHTR AIR (V)	FY-30	SCFM	50.1	58.6	59.3	59.3
	REG NGAS (V)	FY-300S	SCFM	0.22	0.11	0.22	0.22
	REG N2 (V)	FY-310S	SCFM	0.00	0.23	0.00	0.00
FLUID BED COOLER FILE				FBC081	FBC082	FBC083	FBC84486
	FBC AIR VEL	SY-380	FT/SEC	3.00	3.00	3.00	3.14
	AIR (M)	FY-380	#/HR	184.3	183.8	182.3	191.8
	T PLENUM	TE-382	DEG F	970	1000	1000	1000
	T LOWER	TE-383	DEG F	910	920	940	924
	BED DP	PDT-388	H2O	13.62	10.94	11.77	12.78
	PLENUM DP	PDT-387	H2O	5.46	6.24	5.16	5.58
	FBC PRES	PT-386	H2O	1.46	1.78	1.82	2.00
	T UPPER	TE-384	DEG F	911	922	941	925
	T HEATER	TE-381	DEG F	528	568	543	567
	T AIR	TE-380	DEG F	77	77	75	74
	AIR PRES	PT-380	PSIG	2.83	2.90	2.98	2.87
	AIR DP	FT-380	H2O	0.44	0.44	0.42	0.47
	INLET SO2(ADJ)	SO2REF	PPM	2267	2146	2078	2088
	OUTLET SO2(ADJ)	SO2REF	PPM	154	24	157	147
	INLET NOX(ADJ)	NOXREF	PPM	529	528	586	532
	OUTLET NOX(ADJ)	NOXREF	PPM	56	621	586	513
	AIR (V)	FY-380	SCFM	40.3	40.2	39.9	42.0
	TR HOPPER	SSCYCLES	CYCLE	587	1322	1544	268
TEMPERATURE FILE				TEMP067	TEMP068	TEMP069	TEM70671
	COMB AIR T	TE-1	DEG F	76	77	72	73
	CO AIR HTR T	TE-3	DEG F	500	526	526	550
	MOT AIR T	TE-6	DEG F	74	74	56	54
	FUR REFR T	TE-4	DEG F	336	2193	2194	2271
	FURN EXIT T	TE-9	DEG F	1249	366	378	371
	TOT FGAS T	TE-16	DEG F	364	727	354	361
	ABS FGAS T	TE-18	DEG F	748	751	750	750
	HUM EXIT T	TE-27	DEG F	366	366	366	364
	SGHS TOP T	TE-29	DEG F	364	368	367	367
	SGHS BOT T	TE-30	DEG F	367	367	366	364
	ABS Z1 T	TIC-86	DEG F	751	750	750	750
	ABS Z2 T	TIC-88	DEG F	750	750	751	750
	ABS Z3 T	TIC-91	DEG F	750	750	750	750
	ABS Z4 T	TIC-94	DEG F	751	760	760	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750
	CW SUP T	TE-42	DEG F	130	119	116	120
	CW FUR EX T	TE-43	DEG F	148	148	141	46
	CW FGC EX T	TE-44	DEG F	100	79	56	53
	NAT GAS T	TE-20	DEG F	78	80	79	79

TABLE 4. ABSORBER DIFFERENTIAL PRESSURE PROFILES											
Times Top/Middle/Bottom			dP 1-4 "H_2O			dP 1-2 "H_2O			dP 3-4 "H_2O		
12/5 09:46	09:11	07:48	1.4	1.4	1.4	0	0	0	0.6	0.8	0.8
12/6 06:02	06:04	06:06	9.9	10.0	10.3	0	0	0	0.5	0.8	1.0
12/6 06:42	06:40	06:38	15.2	15.3	15.2	0	13	0	0.3	0.4	0.5
12/7 02:40	02:42	02:42	1.8	1.7	1.7	0	0	0.5	1.0	0.6	0.3
12/7 08:29	08:31	08:33	2.9	2.9	2.9	0	0.5	1.0	1.3	0.9	0.4
12/8 01:53	01:52	01:51	3.0	3.2	3.1	0	0	0.5	1.5	0.8	0.8
12/8 N/A	11:11	11:09	N/A	5.0	5.0	N/A	N/A	2.0	N/A	1.1	1.4
12/8 13:08	13:06	13:04	5.6	5.2	5.6	2.0	2.0	0.5	1.7	0.7	2.0
12/9 23:14	23:13	23:12	4.1	4.0	4.1	0	0	0.5	3.0	1.5	1.2
12/9 03:13	03:10	03:09	4.6	4.5	4.6	0	0	0.5	1.1	2.5	2.4
12/9 04:14	04:15	04:16	3.8	3.8	4.0	0	0	0.8	1.8	1.2	1.6
Note: 12/8 11:09 differential pressure profile interrupted by fire alarm in B84 highbay.											

TABLE 5. SORBENT ASH COLLECTIONS										
	Date	Furnace Pot	Absorber In Pot	Absorber Out Pot	Furnace Baghouse	FBH Baghouse	FBC Cyclone	TOTAL Ash	Coal Burnt	Ash/Coal
Weight (lbs.)	5-Dec		3.70	13.40				17.1		
% of ash			21.64%	78.36%						
Weight (lbs.)	7-Dec	39.20	3.00	6.00	25.70	36.20		110.1	899.8	12.24%
% of ash		35.60%	2.72%	5.45%	23.34%	32.88%				
Weight (lbs.)	8-Dec	19.80	3.00	4.60	4.80	0.60		32.8	478.7	6.85%
% of ash		60.37%	9.15%	14.02%	14.63%	1.83%				
Weight (lbs.)	9-Dec	13.10	3.80	2.40	4.00	35.60		58.9	526.6	11.18%
% of ash		22.24%	6.45%	4.07%	6.79%	60.44%				
Weight (lbs.)	11-Dec	1.2	1.4	1.1	0.8	9	4	17.5		
% of ash		6.86%	8.00%	6.29%	4.57%	51.43%	11.43%			
TOTAL	7-11	73.3	11.2	14.1	35.3	81.4	4	219.3	1905.1	11.51%
% of ash	Dec	33.42%	5.11%	6.43%	16.10%	37.12%	0.91%			
Total Sorbent Attrition (lbs., from Table VIII.)								67.3		
Attrition corrected for 5 Dec removal (before ash introduction)								50.2		2.64%

TABLE 6. Sorbent Inventories, Cycles, and Calculated Attrition - MBCUO-07

Sorbent Inventory										
Date	4-Dec	4-Dec	5-Dec	5-Dec	6-Dec	7-Dec	7-Dec	8-Dec	9-Dec	TOTAL
Time	4:14	23:25	13:45	21:44	6:49	6:27	17:10	5:40	6:20	
Sorbent bulk density (lb/ft^3)	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	
Reg. residence time (min.)	120	120	120	90	90	90	90	90	60	
Sorbent Flow (lb/min)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	
Reg. inventory (lbs.)	105	105	105	83	83	83	83	83	60	
FBC inventory (lbs.)	37	37	37	37	37	37	37	37	37	
FBH inventory (lbs.)	58	58	58	58	58	58	58	58	58	
Absorber inventory (lbs.)	146	146	146	146	146	146	146	146	146	
Total Sorbent Inventory (lbs.)	347	347	347	324	324	324	324	324	302	
Change in sorbent inv. (lbs.)	0	0	0	23	0	0	0	0	23	45
Sorbent Additions										
Sorbent Added (lbs.)	0	19.8	0	0	0	0	9.2	0	0	29
Sorbent Removals										
Test Condition Ending			1		2	4		5	6	
Number of 8 oz samples	0	0	12	0	0	12	0	2	2	
Sample Weight (lbs.)	0.00	0.00	2.87	0.00	0.00	2.87	0.00	0.48	0.48	6.70
Attrition										
Difference due to attrition (lbs.)		19.80	-2.87	22.50	0.00	-2.87	9.20	-0.48	22.02	67.30
Sorbent Transport System Data										
Cumulative Transport Cycles	0	335	610	647	762	1332	1466	1680	2085	
Cycles since last change	0	335	275	37	115	570	134	214	405	
Sorbent Weight/hopper (lbs.)			1.58		1.58	1.58		1.58	1.58	
Number of sorbent changes/test condition			2.78		0.74	2.78		1.70	2.12	8.00
Elapsed time since last change	0	19:11	14:19	7:59	9:04	23:38	10:43	12:30	0:40	

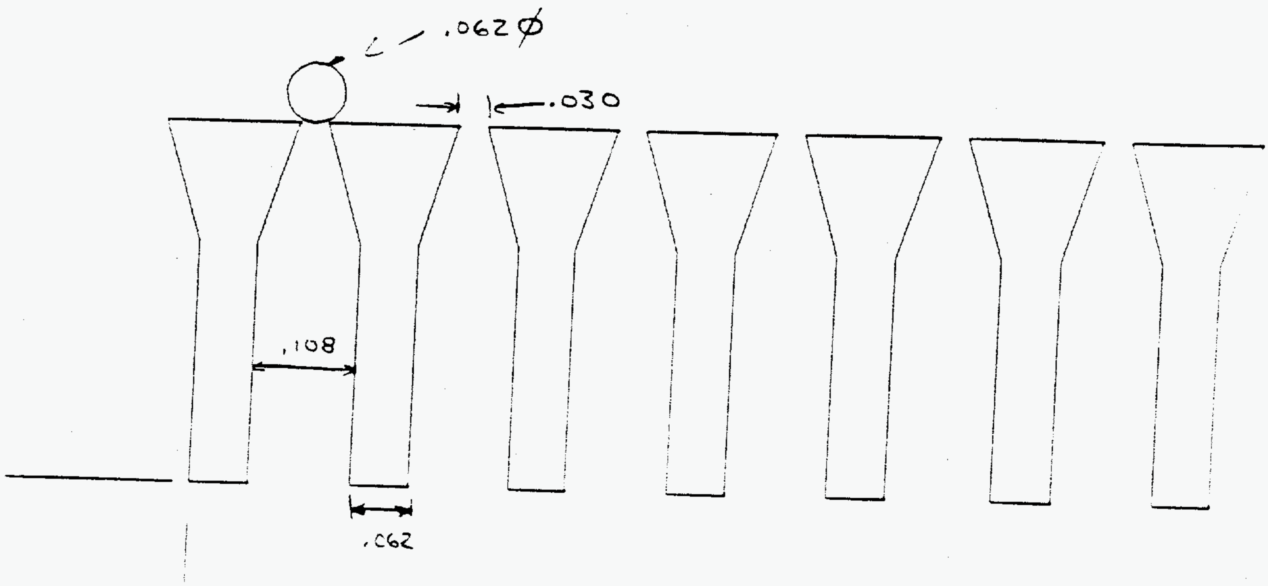

Figure 1: Cross Section of Hendrick Bar Screen.

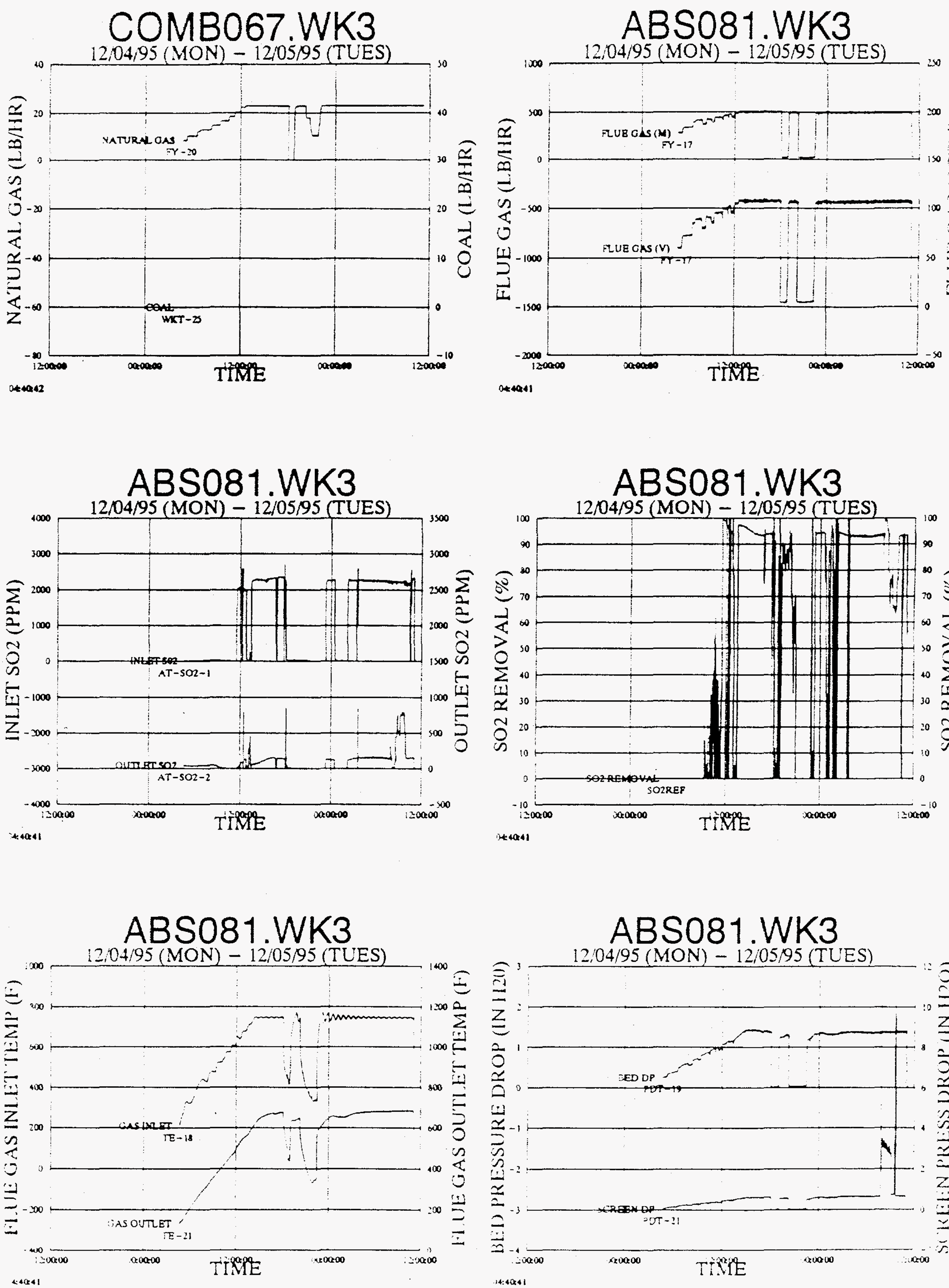

Figure 2: LCTS process variables versus time for test condition #1.

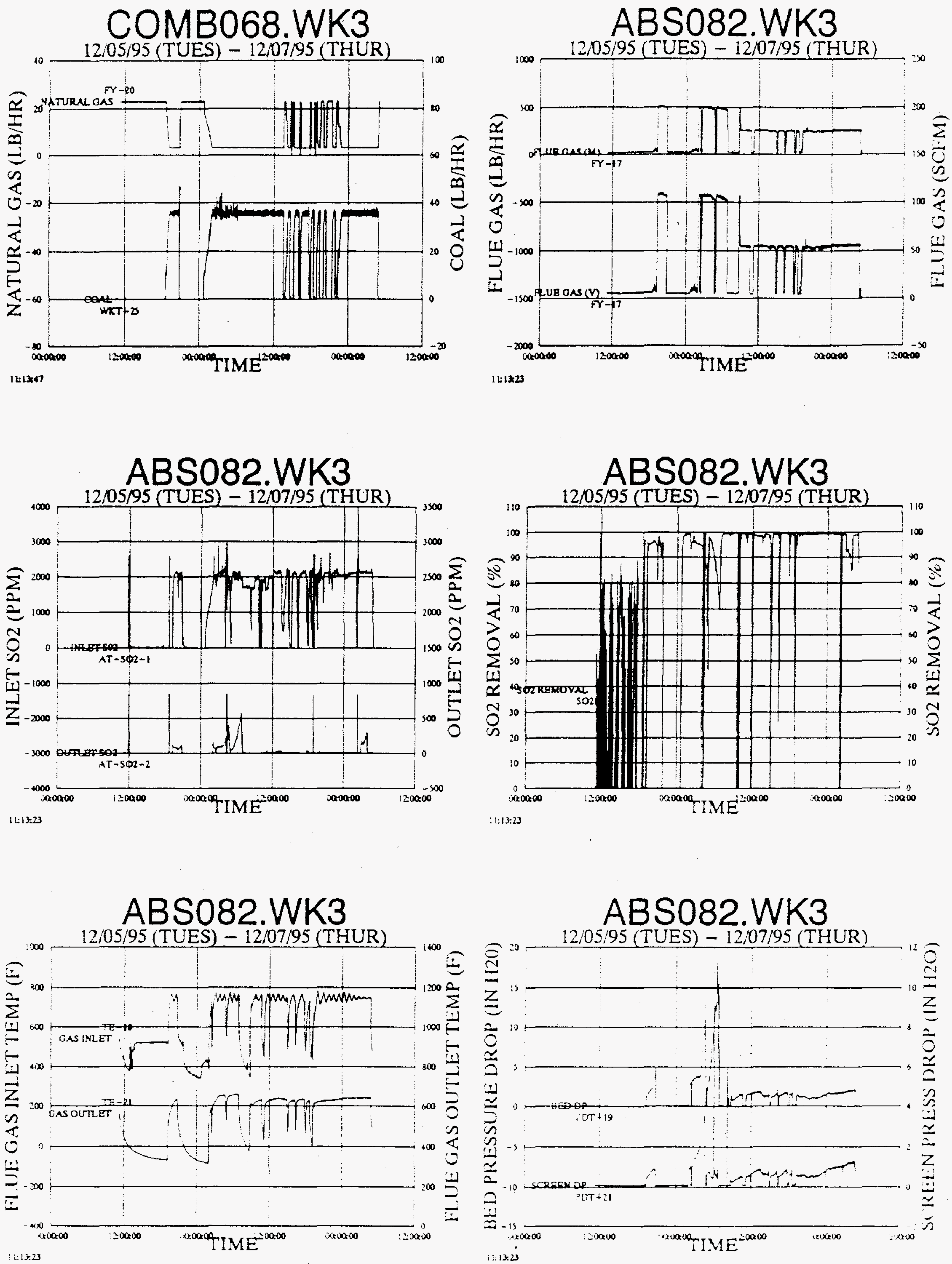

Figure 3: LCTS process variables versus time for test conditions #2 & #4 combined.

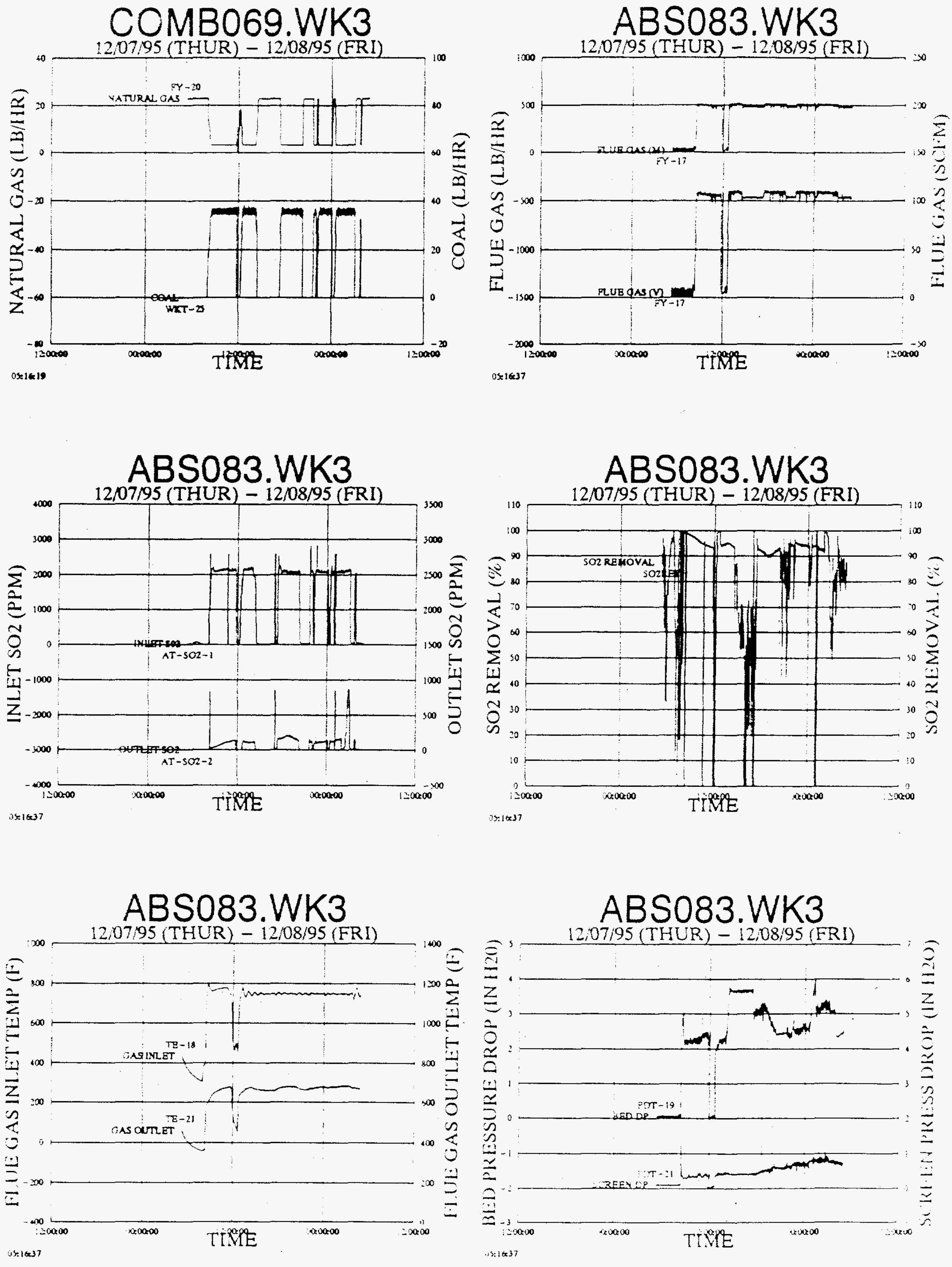

Figure 4: LCTS process variables versus time for test condition #5.

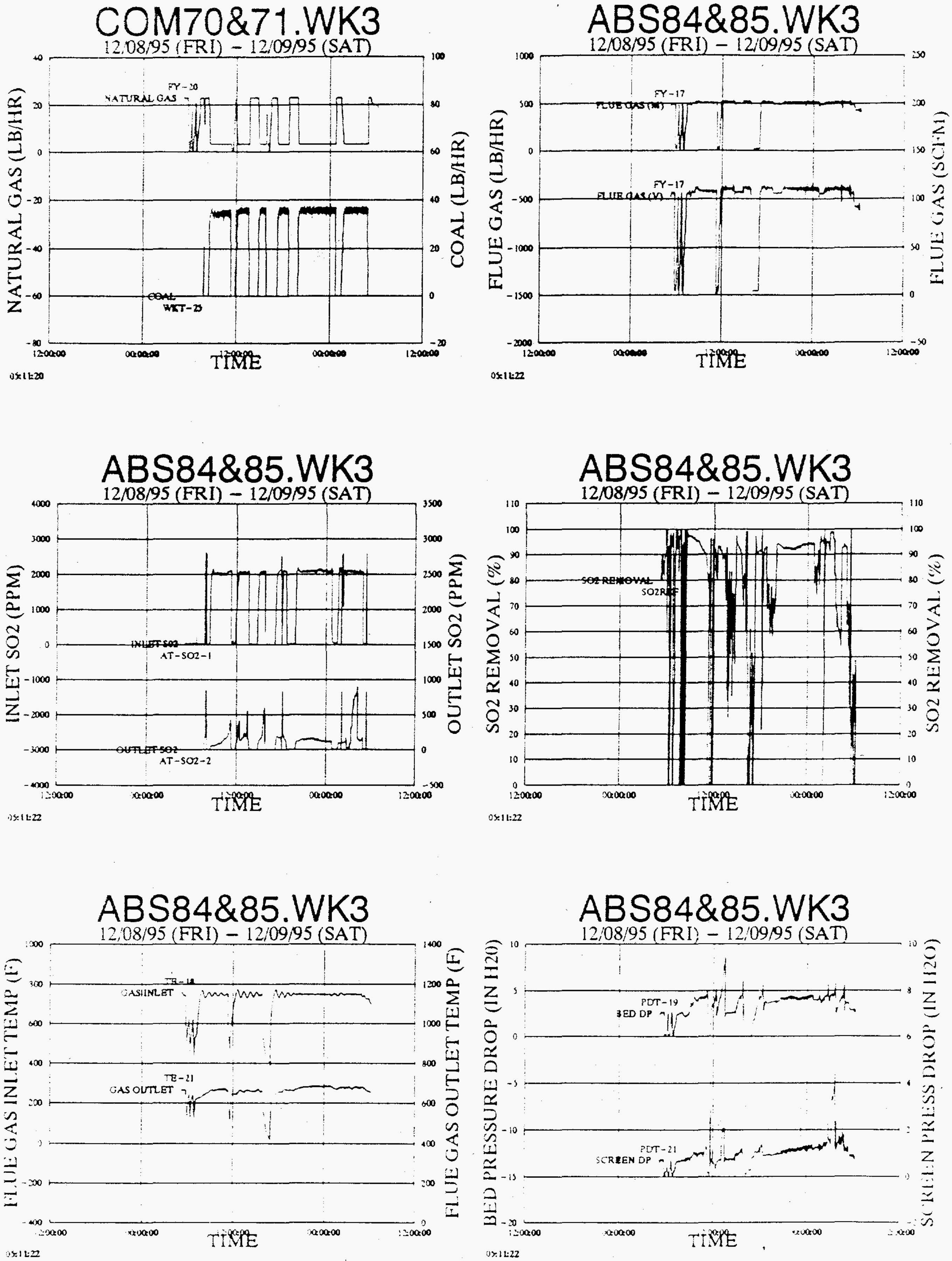

Figure 5: LCTS process variables versus time for test condition #6

PETC INTERIM REPORT III: August 1996
CRADA PC-95006

RESULTS OF ALCOA SORBENT TESTING IN THE LCTS DURING JANUARY TO APRIL 1996

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I. BACKGROUND

Rather than the 1/16-in-diameter sorbent pellets that were used in past tests, the use of larger sized sorbent pellets as a way to reduce pressure drop across the moving-bed absorber was proposed by members of the Moving-Bed Copper Oxide Process (MBCUO) CRADA consortium. Sorbents with different diameters were recommended for use in the LCTS. The relationship between sorbent size and reaction rate for SO_2 removal was also correlated by Tecogen. PETC responded by conducting an engineering evaluation on the operability of the larger sized sorbent in the existing LCTS, followed by testing with the sorbent.

The sorbent was provided by the Aluminum Company of America (ALCOA) under a separate agreement (CRADA PC-93007) with DOE that fulfilled an obligation of ALCOA. Although the two CRADAs with DOE are autonomous agreements, communication between the two industrial-side CRADA parties has developed to the point that ALCOA provided sorbent for a larger-scale development effort of this flue gas cleanup technology.

In this interim report, the results from several process parametric test series (MBCUO-8 through MBCUO-10) with the ALCOA sorbent in the LCTS are discussed. The effects of various absorber and regenerator parameters on sorbent performance (e.g., SO_2 removal) were investigated. Flue gas was produced by burning natural gas or coal. Sorbent spheres of 1/8-in diameter were used as compared to 1/16-in sized sorbent of a previous study [1]. Also referenced are modifications to the absorber to improve the operability of the LCTS when fly ash is present during coal combustion. The experimental results from these modifications are discussed.

II. EXPERIMENTAL

The process has been investigated using the LCTS, which has been described previously [2]. The LCTS has the capability of operating in a continuous integrated mode, specifically related to the absorption and regeneration steps. The sorbent performance in the moving-bed configuration has been characterized by using flue gas that can be produced by combusting natural gas or by combusting pulverized coal (34 lb/hr of an Illinois Old Ben Mine No. 24) with some natural gas support, resulting in a nominal flue gas flow rate of 110 scfm. The flue gas is spiked with SO_2 and NO supplied from cylinders to adjust these concentrations to those of the desired absorber inlet test levels. Ammonia is injected into the flue gas upstream of the absorber to facilitate the catalytic reduction of nitrogen oxides to nitrogen and water vapor in the absorber. The sorbent process stream in the LCTS involves a closed-loop cycle of sorbent transported through four major vessels: the moving-bed absorber, a fluidized-bed sorbent heater, the regenerator, and a fluidized-bed air cooler. Sorbent hoppers located between the vessels isolate the activities occurring in each vessel and provide for metered transport of the sorbent around the closed-loop cycle.

Modifications to the LCTS were required to effectively transport, heat, and cool the larger and denser ALCOA sorbent. There were two concerns related to circulating the larger-sized sorbent. First, the fluidization gas velocities in the fluidized-bed sorbent heater and the fluidized-bed sorbent cooler needed to be doubled-to-tripled to fluidize the 1/8-in-diameter sorbent spheres. The available capacity of each respective blower for the fluidized beds was not able to provide the required flow. Second, it was uncertain whether the solid transport piping lines and hoppers could handle the large diameter spheres, especially when the sorbent bulk density was 54 lb/ft^3 as compared to the past sorbent with density about 35 lb/ft^3.

After fluidization engineering calculations, it was concluded that the existing blowers could not handle the 1/8-in-diameter particles. A solution to the first concern was to insert a liner/sleeve into each fluidized-bed vessel to reduce the cross sectional area. However, by reducing the volumes in the heater and cooler (thus reducing the sorbent residence times in these vessels), a potential existed for poorer heat transfer with the larger 1/8-in spheres. From actual temperature data during the testing, this potential problem did not appear during the MBCUO-8 to MBCUO-10 test series, when the sorbent rates were between 0.75 lb/min to 1.5 lb/min. With respect to the second concern, a batch of raw ALCOA alumina (substrate) pellets was actually tested in the transport lines and hoppers to gain operational and handling experience. With modification (enlargement) of the restricting flow orifices, the 1/8-in spheres were successfully transported.

Previous modifications to the absorber were made to facilitate operation while burning coal. In the original absorber design, sorbent performance in the absorber would degrade as fly ash accumulated within the bed and/or on the sorbent retention screens. Removal of SO_2 in the absorber typically decreased while pressure drop through the absorber increased and effective absorber cross-sectional area decreased. Two modifications were made to the absorber to negate this problem: a new design of the sorbent retention screens and an increase in the pulsing capability of the absorber.

The initial design of the sorbent retention screen (an inlet and outlet screen envelop the moving-bed of sorbent in the absorber) incorporated a square, stainless steel wire mesh (35 mesh -- 0.0176-in square opening by 0.011-in wire diameter) affixed by tack-welding to a stainless steel perforated plate (0.125-in thick, 1-in diameter holes on a hexagonal pattern with 1.25-in center-to-center spacing). However, due to the aforementioned ash plugging problem, a new retention screen design using vertical bars fabricated by Hendrick Manufacturing Company was conceived. The new retention screen consists of stainless steel vertical bars spaced slightly apart, resulting in vertical slots that retain particles of a certain diameter. The cross-sectional area of each bar is shaped like a truncated "golf tee" so that any particle able to penetrate the minimum slot opening encounters a diverging nozzle arrangement, and thus the particle is free to migrate to the opposite side of the screen. At the sorbent/screen interface, the bar measures 0.140-in width, and the bars are spaced 0.030-in apart (i.e., the minimum slot opening) so that particles less than 0.030 inches slip through the minimum slot opening. This modification was made before MBCUO-7 and is described in detail elsewhere [3].

A design change to the back-pulser assembly was also incorporated. The original assembly consisted of eight chambers segmenting the cross-sectional area of the rear retention screen. Each chamber provided screen coverage of 6-in bed width by 4-ft bed height. Two horizontal rows, each containing 4 chambers, provided total screen coverage of 2-ft bed width by 8-ft bed height. Each chamber contained one venturi nozzle to deliver the back-pulse. In an effort to minimize any flow disruption to the furnace, the chambers were sequenced to pulse such that only a quarter of the total bed area was back-pulsed at one time. An increase in back-pulsing capability was implemented before MBCUO-6 by doubling the number of venturi in each chamber from one to two. Also, better sealing of the chamber to the rear screen was incorporated.

III. CHARACTERIZATION OF ALCOA SORBENT

A. Physical Description

ALCOA alumina is the base substrate of the copper oxide sorbent. The copper oxide sorbent was prepared by ALCOA by exposing the substrate to a copper sulfate solution via an incipient wetness technique. The copper sulfate/alumina spheres were then dried in air. The fresh sorbent used in the testing and as received by PETC contains approximately 6.6% copper by weight. The bulk density of the virgin sorbent was about 54 lb/ft^3.

B. Activation of ALCOA Sorbent

1. Sulfur and Copper Analyses -- Fresh Sorbent

Four drums of fresh sorbent were originally shipped to PETC in January 1996. Each drum was sampled and analyzed for copper and sulfur content. Results are given below.

	Cu% by wt	S% by wt
Drum #1	6.7	3.4
Drum #2	6.6	3.4
Drum #3	6.5	3.4
Drum #4	6.6	3.3

The above data indicate that the copper and sulfur weight percentages are in agreement with copper sulfate molecules impregnated on alumina substrate. The average sulfur content is very close to the theoretical 3.33 wt% assuming a 6.6 wt% copper loading.

The fresh ALCOA sorbent was also analyzed at PETC for free water and water of hydration. Fresh sorbent was initially heated in a furnace at 120°C for 1 hr to determine free water; the weight loss was 0.4%. The sorbent was heated for an additional hour at 400°C and the total weight loss of the sorbent was recorded at 4.8%. From an original copper loading of 6.87% as reported by ALCOA, water of hydration loss can range from 1.95% (assuming a monohydrate) to 9.74% (assuming a pentahydrate). It would appear that the water of hydration for the large batch of sorbent falls between the monohydrate and pentahydrate. If the sulfate was in the form of a monohydrate and using the PETC 6.6 wt% number, the calculated Cu as CuO (after total regeneration of the copper sulfate and oxidation of the copper) would be 7.35 wt%; if in the form of a pentahydrate, the calculated Cu as CuO (after total regeneration of the copper sulfate and oxidation of the copper) would be 8.02 wt%.

2. Sulfur Analysis of Regenerated Sorbent

From previous small-scale work with alumina impregnated with copper sulfate, the initial regeneration (activation) rate of the fresh sorbent was lower compared to subsequent regenerations. With this information, the first activation of the sorbent was conducted by circulating the entire sorbent inventory in the LCTS over a period of time. Subsequent activations of the sorbent were conducted in batches in the LCTS regenerator.

The first batch of fresh ALCOA 1/8-in diameter sorbent was activated with natural gas at a regeneration temperature of 850°F. The entire LCTS was loaded with fresh sorbent and the sorbent was circulated at normal process conditions but without SO_2 in the flue gas. Flue gas was produced by burning natural gas. The first activated sorbent sample was taken on 11:50 AM, 1/19/96, after 24 hours at activation process conditions, and the sulfur content was 1.41%. The second activated sorbent sample was taken on 12:00 noon, 1/20/96, after an additional 24 hours at activation conditions, and the sulfur content was 1.16% and the copper content was 6.7%.

Subsequent batch activations occurred at various times during the span of MBCUO-8 through MBCUO-10. Results are shown in Table 1. The batch regenerated sorbent did have a residual sulfur content. It can be speculated that either the fresh sorbent is not being regenerated entirely, or some of the alumina substrate is reacting with the sulfate from the copper sulfate during activation, thus sequestering the sulfur.

Sulfur and copper contents in the ALCOA regenerated samples, that were taken at various steady-state conditions during MBCUO-8 through MBCUO-10, revealed several details. (See Table 2.) The sulfur content of the activated or regenerated sorbent was never less than 1.0% possibly indicating that 1) the copper was not regenerated entirely or 2) some of the residual sulfur is sequestered in the alumina substrate. Also, the copper content of the spent sorbent was always near 6.6%, signifying that the spent sorbent would have the same copper loading as the fresh sorbent. Possible rehydration of water on the sorbent could occur, although a better explanation is not available at this time.

C. XPS Analysis

Samples of sorbent were sent to a PETC laboratory for surface studies. The technique, X-ray photoelectron spectroscopy, was used in the past to determine if the impregnation step was uniform across the pellet; to determine if the process (dusting?) has changed the uniformity across the pellet; to determine the oxidation states of the elements and ions present; and to determine if fly ash constituents are present on the sorbent. This data was informative in relation to the uniformity of the impregnation step and a determination of changes with time on stream for the sorbent.

Table 3 is a listing of the results of a fresh sorbent, a fresh activated sorbent from a circulating activation at the beginning of MBCUO-8, and samples taken after the absorber in MBCUO-9. The outside surface of the pellet was analyzed; the pellet was then cleaved and the core analyzed. Atomic ratios (intensities) are reported. For the fresh sorbent, the Cu 2p spectra showed that Cu was in the 2+ oxidation state. The Cu was very well dispersed on the surface of the fresh sorbent as evidenced by the high value of the Cu 2p/Al 2s intensity ratio. The majority of Cu on the fresh sorbent was located on the outside surface of the spheres as opposed to the inner core.

The outside surface of the newly activated sample appears to have a mixture of all Cu oxidation states (2+, 1+, and 0). There is virtually no Cu 2+ in the core of these spheres. As evidenced by the much lower Cu 2p/Al 2s intensity ratios, especially on the outside of the spheres, the copper has either been sintered or removed as compared to the fresh sorbent. It must be remembered that this sorbent was activated for about 48-hr by regeneration of the circulating sorbent in the LCTS. (See Section IV. A. for details during this operational phase.)

The amount of copper dispersed on the MB9-7 sample was poorer than for the fresh sorbent. Cu was in the 2+ oxidation state. For the spent sorbents, typically little difference was evident between the inner core and outer shell copper loadings.

Sulfur is present as a sulfate in all of the sorbents. The majority of sulfur tends to remain at the outer surface of the spent samples.

There did not appear to be any traces of fly ash in the survey spectra of the outside surfaces of any of the samples. Silicon is expected to be the best indicator of ash deposition on the surface of the spheres. The limit of detection was about 2 wt% for the survey scans.

IV. OPERATIONS OF THE LCTS -- CHRONOLOGY

Three parametric test series -- MBCUO-8, MBCUO-9, and MBCUO-10 -- were conducted during this reporting period. A discussion of the operations follows.

A. MBCUO-8

Fresh 1/8-in diameter ALCOA sorbent was tested for the first time during the MBCUO-8 test series. The fresh sorbent was first loaded into the LCTS; the combustors and reactor electric heaters were fired up on the early hours of 1/16/96. It required some initial learning to move this hard-to-fluidize sorbent around the life-cycle loop. Once this was accomplished, another objective was to activate the fresh ALCOA sorbent, which was impregnated with copper sulfate. The sorbent was activated with natural gas at a regeneration temperature of 850°F. Natural gas flow rate was maintained at about 0.6 lbs/hr throughout the activation procedure. While the sorbent was circulating around the life-cycle system, the entire sorbent inventory in the LCTS was slowly being regenerated. The regenerator off-gas SO_2 and CH_4 concentrations were monitored for regeneration progress. The first sorbent sample was withdrawn on 11:50 AM, 1/19/96, and was sent for rush analysis for sulfur content (1.41% by weight). A second sorbent sample was withdrawn on 12:00 noon, 1/20/96, and the sulfur content was 1.16%. At this time, test condition #1 was started. Due to cold weather, the cylinder of liquid SO_2 located in the unheated cylinder room was unable to deliver enough SO_2 to spike the flue gas to 2250 ppm SO_2. Therefore, the test condition was change to 1500 ppm SO_2 in the flue gas. This test condition was labeled #5 (see Table 4). After test condition #5, test condition #1 was performed. Test condition #1 was followed by test condition #3, that employed coal firing. During coal firing, the absorber pressure drop increased from less than an inch water to about 5-in water. Test condition #1A was a revisit to test condition #1 by returning to natural gas firing at the end of test condition #3.

The reduced data for MBCUO-8 are shown in Table 5. Specifics of the testing follow.

<u>MBCUO-8-5</u>: 1/20-21/1996 Natural gas firing

Test parameters are shown in Table 4. There was no matching test condition when using UOP or Grace sorbents. Pressure drop change across the absorber during this period remained under 1-in water. At 1529 ppm SO_2 inlet and 0.75 lb/min sorbent flow rate, the SO_2 removal was 95.5%.

<u>MBCUO-8-1</u>: 1/22-23/1996 Natural gas firing

During this test period, the SO_2 spike was increased from 1529 ppm to 2246 ppm and the SO_2 removal decreased to 86.8%. Absorber pressure drop remained below 1-in water. Bed pressure drop and SO_2 removal history during this test condition are shown in Figure 1. NO_x removal was tested during this period, and 95.7% NO_x removal was obtained at a comparable NH_3 flow rate as when other sorbents were used. This test condition is comparable to test MBCUO-4-4 when UOP sorbent (6.4% Cu) was used. The SO_2 removal in MBCUO-4-4 was 84%. The disadvantage of larger particle size effect seems to have been compensated by larger sorbent inventory (sorbent residence time) in the absorber. The sorbent inventory ratio (sorbent bulk density ratio) is 54/35 = 1.5 and is in favor of the higher bulk density particle.

MBCUO-8-3: 1/24-25/1996 Coal firing

Flue gas was produced by burning the Illinois Old Ben Mine No. 24 coal during this period. The objective was to observe the effect of larger sorbent size on fly ash retention and on absorber pressure drop. Figure 1 shows the effect fly ash has on the absorber bed pressure drop and the subsequent effect on SO_2 removal. Figure 1 also shows that the pressure drop and SO_2 removal efficiency are very sensitive to back-pulsing, with the response almost instantaneous. Under coal-firing, the SO_2 removal has dropped to 77.1% at 5-in water pressure drop. However, NO_x removal did not seem to be affected.

MBCUO-8-1A: 1/25-26/1996 Natural gas firing

Condition #1 was revisited by halting coal firing and returning to full natural gas firing to produce the flue gas. Figure 1 shows the effect of removing fly ash from the flue gas on SO_2 removal and pressure drop. Fly ash was continuously removed from the LCTS through the fluidized-bed heater during the sorbent circulation, causing the pressure drop across the absorber to decreased to below 1-in water. However, it should be noted that the exponential decrease in the beginning of Test Condition #1A occurred with no back pulsing. After a single quick pulse, pressure drop went below 1-in water and remained there, although additional pulses from time to time were required. SO_2 removal efficiency gradually steadied to 85.7%.

B. MBCUO-9

MBCUO-9 was the second test series for the 1/8-in diameter ALCOA sorbent. Natural gas firing and coal firing were both used to produce flue gas at separate test conditions. Absorption process parameters studied were sorbent flow rate and SO_2 spike level. Sorbent residence time in the regenerator was fixed at 3 hours, because sorbent regeneration appeared unsatisfactory during MBCUO-8 with 2 hours sorbent residence time. Figure 2 shows the pressure drop and sulfur dioxide removal efficiencies with time for selected periods in MBCUO-9.

Specifics of this test follow. Reduced data are shown in Table 6.

MBCUO-9-1: 2/22-23/96 Natural gas firing

The SO_2 removal was 84.8% at this baseline condition. Pressure drop across the absorber was in the range of 0.8 to 1-in water.

MBCUO-9-2: 2/23-24/96 Natural gas firing

Sorbent flow rate was increased from 0.75 lb/min to 1 lb/min, resulting in increased SO_2 removal (from 84.8% to 92.6%) with a corresponding decrease in sorbent utilization (from 59% to 49.2%).

MBCUO-9-8: 2/25-26/96 Coal firing
At 1 lb/min sorbent feed rate and at constant back pulsing, 92.2% SO_2 removal efficiency was reached. Pressure drop across the absorber bed and across the outlet screen were both below 1-in water with constant back pulsing.
MBCUO-9-5: 2/26-27/96 Coal firing
Sorbent feed rate was increased from 1 lb/min in MBCUO-9-8 to 1.5 lb/min. At the same time natural gas flow rate to the regenerator was increased from 0.6 lb/hr to 0.8 lb/hr. SO_2 removal increased from 92.2% to 97.8%. Pressure drop of less than 1-in water was maintained across the absorber and across the outlet screen with constant back pulsing.
MBCUO-9-9: 2/27-28/96 Coal firing
After the SO_2 spike level was increased from 2050 ppm to 3000 ppm, the SO_2 removal decreased from 98.7% to 93.2%.
MBCUO-9-10: 2/28-29/96 Coal firing
In this test condition, sorbent feed rate was reduced to 0.75 lb/min, producing a SO_2 removal of 72.8% as compared to the previous 93.2%.
MBCUO-9-7: 2/29-3/1/96 Natural gas firing
The objective of this test condition was to return to the baseline (MBCUO-9-1) by terminating coal firing. SO_2 removal of 86.6% was achieved, which was comparable to the baseline removal of 84.8%.

C. MBCUO-10

This test series concentrated on a study of sorbent regeneration parameters. Parameters studied included sorbent residence time in the regenerator, natural gas regenerant flow rate, and regeneration temperature. Sorbent flow rate was maintained at 0.75 lb/min throughout this test series. A batch of 322 lbs of fresh ALCOA sorbent was regenerated prior to the formal beginning of this test series. The regenerated sorbent was used as make-up required by attrition. Test Condition #1, MBCUO-10-1, was a repeat of baseline conditions MBCUO-9-1 and MBCUO-9-7. This was followed by Condition #3 in which the regenerant to sulfur equivalence ratio was decreased from about 2 to 1.37. In Condition #4, the regeneration time was reduced from 3 hours to 2 hours. In Condition #5, the temperature of the regenerator was reduced to 800°F but with increased sorbent regeneration time and regenerant to sulfur molar ratio. In condition #7, regeneration time was reduced to 1 hour with reduced regenerant to sulfur ratio but at a higher (850°F) regeneration temperature. This was followed by coal firing in Conditions #8A and #8C at the baseline condition parameters. Figure 3 shows the pressure drop and sulfur dioxide removal efficiencies with time for selected periods in MBCUO-10.

Specifics of this test follow. Reduced data are in Table 7.
MBCUO-10-1: 3/21-22/1996 Natural gas firing
At this baseline condition, sulfur dioxide removal was 86.4% and agreed very well with other baseline periods (MBCUO-9-1 and MBCUO-9-7 with 84.8% and 86.6% SO_2 removal efficiencies, respectively). Absorber pressure drop remained low at less than 1-in water.

MBCUO-10-3: 3/22-23/1996 Natural gas firing
The regenerant to sulfur equivalence ratio was reduced from 2 to 1.37 while other test parameters remained unchanged. SO_2 removal efficiency dropped from 86.6% to 84.8%. Excess methane concentration in the regenerator off-gas dropped from 14% in MBCUO-10-1 to 6% in MBCUO-10-3.

MBCUO-10-4: 3/23-24/1996 Natural gas firing
Sorbent regeneration time was reduced from 3 hours to 2 hours for this condition. Other test parameters remained constant. SO_2 removal efficiency increased to 87.1% from 84.8%. This result was contrary to our expectation that shorter sorbent residence time in the regenerator should produce a poorer regenerated sorbent, and this in turn should produce a poorer effective sorbent in the absorber.

MBCUO-10-5: 3/24-25/1996 Natural gas firing
The regenerator temperature was decreased to 800°F but at increased natural gas to sulfur equivalence ratio (from 1.27 to 2) and regeneration time (from 2 hours to 3 hours). SO_2 removal was 83% compared with 87.1% removal in MBCUO-10-4.

MBCUO-10-7: 3/26-27/1996 Natural gas firing
The regeneration temperature was 850°F at a 1 hour sorbent residence time and a natural gas to sulfur equivalence ratio of 1.37. The SO_2 removal was 82% compared to 87.1% SO_2 removal at 2 hr regenerator residence time.

MBCUO-10-8A: 3/27/1996 Coal firing
The baseline condition, MBCUO-10-1, was repeated but this time with coal firing as compared with natural gas firing. The average SO_2 removal of 86.5% was obtained with constant back pulsing versus 86.4% during MBCUO-10-1, which was with natural gas firing. Pressure drop across the absorber under continuous back pulsing was about 1-in water.

MBCUO-10-8B: 3/27-28/1996 Natural gas firing
To establish the upper limit of sulfur that can be retained on the sorbent, a slot of time was allocated to try to fully sulfate the sorbent in the absorber. If the sulfur on the sorbent exceeds the theoretical amount that can be retained in the form of copper sulfate, then it may be speculated that the excess sulfur could be in the form of aluminum sulfate. During this period, the sorbent circulation in the LCTS was stopped. Flue gas from natural gas firing was spiked with 2250 ppm SO_2. After 6 hours of sulfation the sorbent was still not saturated. The flue gas at the absorber exit contained about 90% of the inlet SO_2 concentration.

MBCUO-10-8C: 3/28-29/1996 Coal firing
The objective of this period was to return to the baseline condition. Constant back pulsing was employed on the absorber. After 10 hours of operation the SO_2 removal was 84.5%.

V. DISCUSSION OF CHEMISTRY RESULTS FROM LCTS OPERATION

A summary of sorbent performance and operational performance of the LCTS is presented in Table 4 for the absorption and regeneration parametric studies. A similar study was conducted with a 1/16-in diameter sorbent using spiked flue gas from natural gas combustion [1]. However, in the present study, some testing periods were conducted to confirm an adequate performance with the larger sorbent and to validate the design of the modified absorber while burning coal. The absorber bed had dimensions of 8-ft height, 1-ft width, and 5-in depth throughout the testing. Periodically during the parametric testing, a baseline condition was repeated to assure that the activity of the sorbent, as well as the operational response of the LCTS, was maintained. The parameters and calculated quantities in the tables represent the average of the data or calculation over a designated steady-state period. Nitric oxide was injected after certain test period conditions attained steady-state, followed by ammonia injection to reach a desired level of NO_x removal. During coal combustion, spiking with NO was not necessary. (For a more detailed discussion of the data reduction procedure, please see references [1] and [2].)

A. Effect of Coal-Firing versus Natural Gas-Firing

From Figure 1, when the system is operated during coal firing without pack pulsing, the pressure drop in the absorber increases and a corresponding decrease in SO_2 removal occurs. Most likely, as the fly ash accumulates in the bed, a decrease in the effective cross-sectional area proceeds.

For steady-state conditions, the SO_2 removal was not significantly impacted when flue gas produced from coal firing was substituted for that produced from natural gas firing. This is apparent if periods MBCUO-9-2 and MBCUO-9-8 are compared or periods MBCUO-10-1, MBCUO-10-8A and MBCUO-10-8C are compared. (See Table 4.) **Note** that the SO_2 inlet concentration is reported on a dry basis, and to maintain an equal flux of SO_2 between both fuel burning cases, an adjustment was made for a change in moisture content in the flue gas due to fuel substitution. Typically during coal combustion, an increase in absorber pressure drop was experienced due to fly ash accumulation in the bed and/or on the screens, but either continuous pulsing or a pulse after a certain pressure drop was obtained (similar to a baghouse operation) reduced the pressure drop. Data in these cases were averaged at steady state at the low pressure drop during a continuous pulsing operational mode.

B. Absorption Study

During the absorption study in Tests MBCUO-8 and MBCUO-9, the regeneration parameters were typically held at 850°F, a residence time of 180 min, and a natural gas-to-sulfur molar ratio of at least 1. The effects of inlet SO_2 concentration and sorbent flow on the pollutant removal efficiencies in the absorber were systematically investigated. A temperature scan was not conducted since past investigations with copper oxide indicated the optimum temperature of absorption is near 750°F.

The last three periods in MBCUO-8 were not used in the following comparisons since it was felt that the temperature of regeneration was substandard and thus the regeneration of the sorbent was in question. Residual sulfur content on the sorbent appears to confirm this assumption (see Tables 2 and 4). Inexperience in operations with the 1/8-in diameter sorbent led to poor fluidization, if any, in the fluidized-bed heater and thus the low temperatures within the regenerator.

Absorber model predictions were also compared to the actual SO_2 removals at a set of conditions. In general, the 1/8-in diameter sorbent spheres appeared to exhibit more resistance to regeneration compared with the 1/16-in diameter sorbent used in tests prior to MBCUO-8. Tables 2 and 4 show that residual sulfur in regenerated sorbent ranges from about 1.3% to 2% at the regenerator conditions tested. The residual sulfur is about 0.8% higher than when the 1/16-in diameter sorbent was used under similar test conditions. In addition, Dr. Sheila Hedges of PETC reported that the rate constant of a similarly impregnated copper oxide/alumina 1/8-in diameter sorbent is 60% of that obtained from a 1/16-in diameter sorbent [4]. Thus, the absorber model of Young and Yeh [5] has been modified by (1) assuming that 0.8% of sulfur is not regenerable in the 1/8-in diameter sorbent, and (2) the sorbent rate constant is 60% of the 1/16-in diameter sorbent due to pore diffusional effects. (Please caution that the 1/16-in diameter sorbent rate was previously obtained using a UOP sorbent and some differences may exist with the present sorbent.) The resultant model predictions of the absorber performance are listed in Table 4, and the modified model reasonably predicted the absorber performances.

The impact of the inlet flue gas SO_2 concentration was investigated. Essentially, as the SO_2 concentration increases, the effective Cu/S feed ratio decreases, thus causing a decrease in SO_2 removal efficiency. Results can be seen in Table 4 when periods MBCUO-8-5, MBCUO-9-1, and MBCUO-9-10 are compared at the lower sorbent flow rate of 0.75 lb/min, and when periods MBCUO-9-5 and MBCUO-9-9 are compared at the sorbent flow rate of 1.5 lb/min. The concentration levels of SO_2 were nominally 1500, 2250, and 3250 ppm on a dry basis and simulate the concentrations in flue gas when a mid- to high-sulfur coal is combusted. A comparison of these experimental results and the model predictions for a 0.75 lb/min sorbent flow rate is seen in Figure 4.

The effect of changing the sorbent flow on the SO_2 removal efficiency was also investigated. Effects of varying the sorbent flow can be seen at two different inlet gas SO_2 concentration conditions. The first is at a nominal 2250 ppm inlet concentration for periods MBCUO-9-1, MBCUO-9-2, and MBCUO-9-5; SO_2 removals increased with increasing sorbent flow. The second is at a nominal 3000 ppm inlet SO_2 concentration for periods MBCUO-9-9 and MBCUO-9-10. The trend is the same indicating that a higher sorbent flow of regenerated sorbent will enhance the SO_2 removal efficiency of the absorber. Figure 5 depicts actual experimental data versus model predictions.

Several additional items should also be noted with respect to these absorption tests. A return to the baseline conditions after a duration of time (periods MBCUO-9-1 and MBCUO-9-7) indicated that no decrease in sorbent activity occurred during the testing. Also, the reactivity of the sorbent was not impacted when flue gas produced by coal combustion was substituted for that produced by natural gas combustion (periods MBCUO-9-2 and MBCUO-9-8). The revised sulfation model predicted the SO_2 removals quite well as seen in Table 4. Also, NO_x removals were around the designed levels of 90% and 95% as seen in Table 4.

C. Regeneration Study

A regeneration study (MBCUO-10), summarized in Table 7, investigated the effects of temperature, residence time, and natural gas-to-sulfur molar ratio on regeneration. Constant nominal absorption conditions of 110 scfm of flue gas, 750°F, 0.75 lb/min sorbent flow, and 2250 ppm inlet SO_2 concentration were maintained. The effect of temperature can be seen in periods MBCUO-10-1 and MBCUO-10-5 where a 50F° drop in temperature decreases the effectiveness of regeneration, as depicted in the larger concentration of methane in the off-gas and a decrease in absorber SO_2 removal. The impact of sorbent residence time was studied at constant natural gas-to-sulfur ratio and temperature in periods MBCUO-10-3, MBCUO-10-4, and MBCUO-10-7. Although the results appear similar at residence times of 180 min and 120 min, the effectiveness of regeneration diminishes below a residence time of 120 min as determined by an increase in regenerator outlet CH_4 concentration, a decrease in SO_2 removal in the absorber, and an increase in residual sulfur on the sorbent. The influence of natural gas-to-sulfur molar ratios can be determined by comparing periods MBCUO-10-1 and MBCUO-10-3, where the larger ratio condition resulted in the outlet gas diluted with methane. At these two particular ratios, the impact on the overall capacity of the sorbent for SO_2 removal was minimal.

D. Sulfur Balances

Gas phase sulfur balances for the periods in MBCUO-8, MBCUO-9, and MBCUO-10 are shown in Table 8. Steady-state SO_2 removal in mol/hr from the absorber is compared with the steady state regenerator SO_2 off-gas in mol/hr. These gas phase sulfur balances are reasonably good with about 75% of the data within a 10% error range.

Table 8 also compares the solid phase sulfur balance with that from the gas phase balance in the absorbers for the steady-state periods from the three tests. While the error was high for 4 out of 9 test periods in MBCUO-8 and MBCUO-9, the sulfur balances were excellent in MBCUO-10 (less than +/- 10% in error).

VI. ABSORBER PARTICULATE REMOVAL RESULTS

A. Effect of Retention Screen Design and Sorbent Size

Findings of the absorber modification changes with two different sorbent sizes are listed in Table 9. For all the test periods reported in this table, flue gas flow was obtained from natural gas firing of the combustor. The total pressure drop across the 5-in thick bed was the largest with the old retention screen design (2.5-in of water) as compared to the new design (1.4-in of water). The screen substitution did not impact the SO_2 removal but did successfully lower the pressure drop across the absorber. A benefit in going to the larger-sized sorbent is realized by observing the decrease in pressure drop from 1.4 to 1.0-in of water. It is also noteworthy that the sorbent reactivity of the smaller sorbent -- as depicted by the SO_2 removal -- was greater than the larger material. If the assumption is made that the copper reactivity is similar for both sorbents, then these results could indicate that pore diffusional resistance is greater for the larger sorbent. Also, it must be mentioned that the difference in SO_2 removals between the larger and smaller sorbents is not too large. Although one contribution to the difference may be diffusional limitations, it must be realized that because the ALCOA sorbent has a larger bulk density, the residence time within the reactor volume is greater for the ALCOA sorbent. The greater sorbent residence time would enhance SO_2 removal.

B. Coal-Firing and Pressure Drop Effects

Figure 1 shows a comparison between two tests at the same operating conditions but with a different sorbent size (MBCUO-7: 1/16-in sorbent versus MBCUO-8: 1/8-in sorbent). Under natural gas firing, the smaller sorbent has the better SO_2 removal capability. Under coal-firing, two methods of pulsing were conducted: a dead-band pulsing that typically let the bed pressure drop grow to about 6-in water before pulsing to obtain a maximum of 3-in water; and a continuous pulsing of the bed every 30-sec. Steady-state conditions under coal burning were typically obtained during the latter type of pulsing. As can be seen in the dead-band pulsing, as the pressure drop across the bed increases, the SO_2 removal efficiency decreases with time. Pulsing returns the pressure drop to the initial condition obtained under natural gas firing. From the bottom of Figure 1 it should be noted that once coal is shut off and natural gas firing then initiated, the pressure drop will decrease because fly ash that was in the bed is transported out of the bed due to the sorbent flow.

Similar pressure drop and sulfur dioxide removal relationships with time are seen in MBCUO-9 and MBCUO-10 (see Figures 2 and 3, respectively). Under coal firing, continuous pulsing keeps the pressure drop across the bed at the same level as if natural gas were burned. Dead-band pulsing was successful in returning the pressure drop to the initial condition obtained under natural gas firing. In MBCUO-9, it is interesting to note that dead-band pulsing at two different sorbent flows (1.0 and 1.5 lb/min) indicated that as the sorbent flow increased, the frequency of the pulsing decreased. About 2.5 hours per pulse was needed at 1.0 lb/min versus 4 hours per pulse at 1.5 lb/min. This effect -- ash removal as a function of ash loading and sorbent flow rate -- is more dramatic in the most recent testing in MBCUO-11 and MBCUO-12.

An assessment of the absorber (with the bar screen design) to remove ash in coal-combusted flue gas was also investigated during

MBCUO-9 parametric testing using 1/8-in ALCOA sorbent. A baseline test condition utilizing natural gas firing was initially established, followed by four test conditions with coal firing, concluding with a return to the baseline condition with natural gas (see Figure 2). Several methods of back-pulsing the bar screens were investigated. Differential pressure profiles across the absorber (see Table 10) were obtained to aid in identifying the mechanism of ash accumulation within the absorber. The total pressure drop across the absorber (including the front bar screen, sorbent bed, and rear bar screen) was obtained. (Locations of pressure taps can be found in reference [1].) Pressure drop across the rear screen at three different bed heights was measured. Under coal firing, pressure drop would typically grow in the absence of back-pulsing and the SO_2 removal would degrade, indicating that some blinding of the bed due to ash/sorbent was occurring. Once the system was briefly pulsed, the SO_2 removal would quickly spike upward and the pressure drop would decrease. If continuous pulsing was enacted, the pressure drop would remain low and constant with time.

Inspection of data in Table 10 reveals several observations. First, a baseline condition with no ash present results in an overall pressure drop of 0.8 to 1-in water across the absorber. The rear screen accounts for the majority of the pressure drop and is relatively uniform from top to bottom in the absorber. Second, once ash is introduced and no pulsing is enacted, the pressure drop across the rear screen grows non-uniformly. Typically during this "pre-pulse" stage, the rear screen pressure drop is lowest at the bottom and highest at the top. Interpretation of this gradient is difficult because two phenomena can simultaneously occur. High pressure drop could imply high velocity gas through the bed, and it could imply reduced cross-sectional area due to blinding. Without independent velocity measurement, a definitive cause cannot be concluded. Third, the system quickly responds to pulsing (a "post-pulse" stage) with pressure drop returning to about 1-in water. Continuous pulsing (30 second interval between pulsing consecutive chambers) is denoted as "profile" stage, representing the steady state condition under which the absorber is eventually sampled for gas and sorbent composition. At the conclusion of the coal tests, a return to the natural gas baseline condition resulted in similar pressure drop and SO_2 removals encountered at the beginning of the test (MBCUO-9-1).

C. Solids Recoveries and Particle Size Distributions

Bulk solid (dust) balances for various selected periods during the testing are shown in Table 11. Table 12 lists overall solid balances for the entire tests. From this tabulated information, most of the solids appeared in the baghouse from the fluid-bed heater. However, it must be remembered that these balances considered total solids collected and did not distinguish between ash and sorbent fines.

However, ash balances that did consider the sorbent fines present have been calculated for periods in MBCUO-8, MBCUO-9, and MBCUO-10, and are shown in Tables 13, 14, and 15, respectively. Table 16 shows selected periods for sorbent/ash distribution. During coal burning, ash/sorbent fines will accumulate in various vessels: the bottom ash pit to the furnace; the ash hopper on the inlet to the absorber; the ash hopper on the outlet to the absorber; the flue gas baghouse on the exit of the absorber; the baghouse on the heating gas outlet to the fluidized-bed heater; and the cyclone on the fluidized-bed cooler outlet. These vessels were periodically drained, and the collected material was weighed and sampled. Samples were then analyzed for copper content with the intent of distinguishing between coal ash and attrited sorbent.

From the data in the tables, material recoveries were poor, especially from tests MBCUO-9 and MBCUO-10. Inspection of the baghouses after MBCUO-10 revealed that the filter bags in the baghouse on the outlet line from the fluidized-bed heater had holes, possibly explaining the poor solids recoveries. If the assumption can be made for the MBCUO-8-3 period balance that the filters were not damaged, it then appears that the absorber removed roughly 50% of the fly ash and the remaining 50% flows through the absorber and is collected in the flue gas baghouse. New filter bags have replaced the damaged fluidized-bed heater bags prior to test MBCUO-11, which used a 12-in depth absorber. Also, the flue gas baghouse passed an inspection of its bags.

For the MBCUO-10 test period, particle size distributions were found with a Micro-Trac Analyzer for solids obtained from the various hoppers. From this photo-electric technique, an average diameter of the particles can be determined based on the number of particles present. The assumption is that the particles are present as spheres, and the diameter is calculated as a ratio of the volume to outer surface area. The maximum sphere diameter is 300 micron. Results from the hoppers are as follows: the absorber flue gas baghouse -- 7.6 micron; the fluidized-bed heater baghouse -- 54 micron; the fluidized-bed cooler cyclone -- 38 micron; and the absorber inlet ash hopper -- 24 micron. This technique was not able to be performed on the absorber outlet ash hopper since particles greater than 300 micron were present. After seiving and on a weight basis, 89.4 wt % of the particles were between 250 to 1000 micron diameter. These larger diameter particles were most likely sorbent particles that were pushed through the screens in the absorber and then fell to the bottom of the absorber vessel exit. The high copper loading in Table 15 would tend to confirm this. It should also be noted that the samples from the fluidized-bed heater baghouse also had high copper content indicating that some of the attrited sorbent ends up in this vessel.

VII. SORBENT ATTRITION

A. Overall Attrition Rates

During testing, sorbent was typically added on an as-needed basis by observing the pressure drops in the fluidized-bed heater and coolers. Sorbent make-up, that had been activated by reducing it in a batchwise regeneration, was added to the fluidized-bed cooler. In this manner, the total amount of sorbent that was added during a test could be determined, and this is directly related to the attrition. Table 17 summarizes the sorbent attrition information for the three tests. After MBCUO-10, the absorber was drained and samples were taken and later sieved. The average particle size distribution for the sorbent was as follows:

Size Range, in	Wt% of Total
0.0930<x	79.1
0.0469<x<0.0930	17.5
0.0394<x<0.0459	1.72
0.0278<x<0.0394	0.96
x<0.0278	0.65

Mass distribution of dust collections among flue gas baghouse, fluid-bed heater baghouse, fluid-bed cooler cyclone, absorber inlet and outlet pots, and furnace pots can be found in Tables 13, 14, and 15. An attempt was made to compare the sorbent make-up added during the test to the sorbent -- as found by copper analysis -- in these solids collection vessels. The sorbent recoveries in MBCUO-8 and MBCUO-10 were poor, possibly fortifying the finding of baghouse leakage on the fluidized-bed heater outlet.

B. Calculated Attrition Rates

1. Transport System

In the transport system, the sorbent flows from the bottom of the absorber into a transport hopper. Through a sequence of valve actions, the hopper with sorbent present is pressurized with air and then suddenly depressurized to pneumatically transport the sorbent about 35-ft vertically through a 3/4-in external diameter tube to the fluidized-bed heater. Earlier cold investigations of the system revealed that the transport of the sorbent causes part of the overall attrition.

Cold attrition transport studies were conducted with fresh ALCOA sorbent (from the as received drum), used ALCOA sorbent (from the absorber after MBCUO-10), and the substrate. The initial nominal size of the materials used was 1/8-in diameter. The following procedure was used for this testing:

1. Approximately 10-lb of sorbent was sieved through a 0.093-in sieve. The sieve size is about 75% of the 1/8-in nominal diameter of the sorbent sphere. Only the material remaining on the screen was used for the test.

2. The bulk density of sieved sorbent was determined using a 1000-ml graduated cylinder.

3. A baghouse bag was weighed and attached to the outlet of the transport pipe.

4. The transport pressure was set to 12 psig at the regulator. A later test increased this pressure to 15 psig.

5. Four thousand ml of sieved sorbent was weighed and poured into the transport hopper inlet pipe.

6. Two shots of sorbent were sent through the transport system.

7. The sorbent was emptied from the bag and sieved through a No. 25 sieve (0.0278-in opening). The sieve size is near the 0.030-in opening in the absorber retention screen. Fines and sorbent were weighed. The sorbent was returned to the hopper inlet pipe.

8. Steps 6-7 were repeated for a total of 10 transport cycles.

9. After the tenth cycle, the remaining sorbent in the inlet pipe was sent.

10. The sorbent was collected and sieved. The fines, bag, and sorbent were weighed.

Table 18 lists the results of the attrition transport testing that was conducted at room temperature. Several conclusions and observations can be made. First, prior to the testing, the amount of smaller-than-normal sorbent in the used sorbent is much greater than in the substrate batch or in the fresh sorbent batch. Visually, a large portion of the used sorbent that passed through the 0.093 mesh looked to be spheres smaller that the fresh sorbent. Second, the total sorbent fines < 0.0278-in was greatest for the used sorbent. Third, the amount of fines as a function of transport cycle appeared to increase with cycle for the used sorbent as compared to the substrate or new sorbent. And fourth, as has been seen in past attrition transport testing, the rate of attrition was higher at the increase transport pressure.

2. Fluidized-Bed Vessels

With the increased size and density of the 1/8-in ALCOA sorbent as compared to the earlier 1/16-in sorbents, a higher minimum fluidization velocity was needed in the heating vessel and the cooling vessel. It was intuitive that sorbent attrition would be greater at the higher velocity. Two test were conducted to quantitatively identify the attrition rates in these vessels. The first was a cold test of the used 1/8-in ALCOA sorbent that was removed form the absorber following MBCUO-10. The second was a hot test using sorbent also from after MBCUO-10. Both tests were conducted in the fluidized-bed cooler (FBC).

Cold Test

The following procedure was used in the cold testing:

1. The FBC was drained via the drain valve. The FBC blower was started to agitate the remainder of sorbent in the FBC. The FBC was drained again. The process was repeated until no sorbent was removed after an agitation cycle.
2. The FBC blower was run at full flow (7.2 ft/s gas bed velocity) for five minutes to clear the vent line.
3. The sorbent dust was drained from the FBC cyclone, located on the vent line.
4. Used sorbent was sieved to give 40-lb retained on 0.093-in mesh. This sorbent was weighed and added to the FBC.
5. The FBC blower was operated at full flow (7.1 ft/s bed velocity). Twice during the test a motor overload caused the gas velocity to either terminate or flow at a reduced velocity (4.2 ft/s).

6. The remaining sorbent in the FBC was drained (as per step 1) and weighed on the balance. The sorbent was sieved through 0.0278-in and 0.093-in sieves and the splits weighed.
7. The dust from the FBC cyclone was removed and weighed.

Hot Test

The procedure used for the hot test was identical to the previous cold FBC attrition test (above), with the following exceptions:
1. The FBC was operated at 8.3 ft/s gas bed velocity and at a sorbent bed temperature of 1000°F. These conditions simulate those of the actual operation in either the fluidized-bed cooler or the fluidized-bed heater.
2. The attrition test lasted a total of 39 hours at the above flow rate and temperature.
3. After running at the above conditions, the FBC was operated at minimum flow (4.2 ft/s) while the sorbent cooled (for approximately 3.5 hours).

Table 19 lists the results of both the cold and hot attrition testing in the fluidized-bed cooler. From the cold FBC results, first, in 36.3 hours of operation at 7.1 ft/s, the inventory of whole sorbent particles was reduced to 51.2% of the initial value. The sorbent lost over the test was 30.4% of the initial charge. Translated to actual operation, the apparent attrition via the FBC is 0.33 lb/hr. Second, 93.7% of the sorbent loaded into the system was recovered. Assuming the difference was lost through the FBC cyclone, the cyclone efficiency was 79.4%. Third, the bed differential pressure was reduced from 18.7-in H_2O to 13.8-in H_2O This reduction in differential pressure (26.2%) correlates nicely with the loss of sorbent weight in the FBC (30.4%).

Similar results were found after the hot test in the FBC, although the attrition was not as great as during the cold test. First, in 39 hours of operation, the inventory of full sorbent particles was reduced to 66.6% of the initial value. The sorbent lost over the test was 18.1% of the initial charge. Translated to actual operation, the apparent attrition via the FBC is 0.185 lb/hr. Second, 91.5% of the sorbent loaded into the system was recovered. A moisture analysis of the sorbent will be required to determine the cyclone efficiency, as drying was sure to have taken place in this test. Third, the bed differential pressure was reduced from 18.3-in H_2O to 15.3-in H_2O. This reduction in differential pressure (16.4%) correlates nicely with the loss of sorbent weight in the FBC (18.1%).

C. Comparison of Attrition Rates

An attempt was made to combine the attrition rate in the transport system with that in the fluidized-bed vessels and compare this number with the actual rate for each test found in Table 17. The attrition contribution from the transport system was derived from the last column from Table 18, 5.58-gm/cycle. From the fluidized-bed cooler or the fluidized-bed heater, the contribution was determined from the hot test: 0.185-lb/hr each or 0.37-lb/hr for both vessels. From Table 17 and by using the cycles and hours per test, the transport system contributions for MBCUO-8, MBCUO-9, and

MBCUO-10 were 0.10, 0.15, and 0.12 lb/hr, respectively. Adding the fluidized-bed vessels donation to the transport system gives the following for MBCUO-8, MBCUO-9, and MBCUO-10: 0.47, 0.52, and 0.49-lb/hr, respectively. Comparison with the attrition values in Table 17 reveal that the calculated rate for MBCUO-8 was higher than the actual but in the latter two tests, the calculated was lower than the actual. For MBCUO-8, little or no fluidization occurred in the fluidized-bed heater due to inadequate gas velocity through the bed (see Table 5). Thus the attrition due to this vessel was low. For MBCUO-9 and MBCUO-10 the calculated rates are lower than the actual. Explanations for this could be a) an underestimation in the rate calculated for the fluidized vessels; b) as the sorbent ages, it gets smaller and may escape through the absorber sorbent retention screens; and c) a rate underestimation in the transport tests since the tests blew the sorbent into a bag, whereas during actual LCTS operation, the sorbent probably impacts in the fluidized-bed heater vessel. In any event, the contribution of the fluidized vessels is a significant one relating to the attrition rate and was found to be larger than the contribution from the transport system.

VIII. MISCELLANEOUS

Copper oxide/alumina sorbent is known to remove SO_2 from flue gas, and thermodynamically it is purported to more readily remove SO_3 from the flue gas. However, measurements have not been conducted in the past to determine this.

An attempt to measure any SO_3 removal capability of the sorbent was conducted during MBCUO-10. EPA Method 8 for determination of SO_3 in flue gas was used as a basis. In this method, isopropanol was used as the impinger solution. The solution was analyzed using an ion chromatograph.

Samples were obtained immediately before and after the absorber. A probe was not inserted into the flue gas but rather a slip stream was sampled. Results indicated that while under coal burning, the combustor produced about 5.6 ppm SO_3 and the flue gas exiting the reactor contained 0.64 ppm on a dry basis, yielding a removal of about 90%. It must be **cautioned** that only one sample was obtained at each sampling location. However, the trend was that SO_3 was removed across the reactor of sorbent.

IX. SUMMARY

A parametric study of the Moving-Bed Copper Oxide Process was conducted with 1/8-in sorbent in the LCTS. The effects of various parameters on the absorption and regeneration steps of this flue gas cleanup technique were systematically investigated. High removals of SO_2 were obtained at most conditions. A decrease in the inlet SO_2 concentration or an increase in the sorbent flow rate enhanced the SO_2 removal capabilities of the absorber.

Regarding regeneration, a high temperature or a large residence time has a major influence on the regeneration of the sorbent. A new absorber design facilitates the use of particulate-laden flue gas in the current bed configuration.

X. REFERENCES

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[2] Pennline, H.W., Yeh, J.T., Hoffman, J.S., Longton, E.J., Vore, P.A., Resnik, K.P., and F.N. Gromicko, Design, Construction, and Operation of a Life-Cycle Test System for the Evaluation of Flue Gas Cleanup Processes. U.S. DOE Topical Report, DOE/PETC/TR-96-01, December 1995.
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[4] Hedges, S.W., private communication, August 1995.
[5] Young, R.J. and J.T. Yeh, Computer Simulation of a Flue Gas Desulfurization Moving-Bed Reactor. Environmental Progress, 12(3), pp. 200-207, 1993.

XI. LIST OF TABLES AND FIGURES

August 30, 1996

Table 1. Batch Activation During Testing Era

Test No.	Date	Amount of Sorbent lbs	Sorbent Sulfur Content Wt%
MBCUO-8	1/15/96	550	1.2
		(entire inventory circulated during activation)	
MBCUO-9	2/20/96	651 (batch activation)	1.8
MBCUO-10	3/18/96	323 (batch activation)	1.75

Table 2. Analysis of Sorbent Samples

S%, Cu%, Cl% in sorbent samples (ALCOA SORBENT)

MB8	S%/Cu%	MB9	S%/Cu%/Cl	MB10	S%/Cu%
-5-P2 (reg top port) NG 1/21/96	3.3	-1-P2 (reg top port) NG, 2/23/96	3.65	-3-Reg-out-hop NG, 3/23/96	1.5
-5-Reg-out-hopper	1.65	-1-P1 (reg bottom port)	2.35	-3-Trans-hop	3.36
-5-Trans-hopper	3.27	-1-Reg-out-hop	1.76/6.7	-4-Reg-out-hop NG, 3/24/94	1.37
-5-ASV391	2.23	-1-Trans-hop	3.75/6.2	-4-Trans-hop	3.34
-5-ASV397	2.03	-1-ASV397	4.01	-4-ASV391	1.5
-1-Reg-out-hop NG, 1/23/96	2.01	-1-ASV391	2.24	-4-ASV397	3.05
-1-Trans-hop	3.67	-2-P2 NG, 2/24/96	3.85	-4-Reg-top-port	2.84
-1-ASV391	2	-2-P1	3.33	-5-Reg-out-hop NG, 3/25/96	1.55
-1-ASV397	3.95	-2-Reg-out-hop	1.51/6.6	-5-Trans-hop	3.5
-1-P2 (Reg top port)	2.9	-2-Trans-hop	3.13/6.6	-5-ASV392	1.81
-3-Reg-out-hop Coal, 1/25/96	1.68	-2-P3 (reg bottom port)	2.72	-5-ASV397	3.21
-3-Trans-hop	3.24	-8-P1 Coal, 2/26/96	3.33	-5-Reg-bottom-port	2.17
-1A-Reg-out-hop NG, 1/26/96	2.06/6.5	-8-P2	3.15	-7-Reg-out-hop NG, 3/27/96	1.8
-1A-Trans-hop	3.97/6	-8-P3 (reg top port)	3.19	-7-Trans-hop	3.51
		-8-Reg-out-hop	1.36	-8B-ASV391 Coal, 3/28/96	1.3
		-8-Trans-hop	3.07	-8B-ASV392 (batch sulfation in 8B)	4
		-5-Reg-out-hop Coal, 2/27/96	1.5/7.2	-8B-ASV393	4.3
		-5-Trans-hop	3.16/6.5	-8B-ASV394	4.3
		-9-Reg-out-hop Coal, 2/28/96	1.45	-8B-ASV395	4.5
		-9-Trans-hop	3.98	-8B-ASV396	4.1
		-10-Reg-out-hop Coal, 2/29/96	1.33	-8B-ASV397	4
		-10-Trans-hop	3.14		
		-7-Reg-out-hop NG, 3/1/96	1.8		
		-7-Trans-hop	3.5/6.2/LT 0.1%		

SAMPLE	INNER CORE		OUTER SHELL	
	I Cu 2p/I Al 2s	I S 2p/I Al 2s	I Cu 2p/I Al 2s	I S 2p/I Al 2s
Fresh Sorbent #1	1.07	0.19	37.5	2.93
Newly Activated - 1/20/96	0.68	0.02	1.08	0.08
MB9-7-Transport - 3/1/96 Natural Gas Firing	1.36	0.16	1.40	0.43
MB9-8-Transport - 2/26/96 Coal Firing	1.39	0.13	1.19	0.52
MB9-10-Transport - 2/29/96 Coal Firing	1.52	0.07	0.81	0.33

Table 3. XPS Results

Table 4. Data Summary of Tests MBCUO-8, MBCUO-9, and MBCUO-10

1/8" bead 5" bed	fuel	F.G. scfm	sorbent feed #/min	absorber temp °F	SO2 inlet ppm	SO2 removal eff% experiment	SO2 removal eff% model	NO_x inlet ppm	NO_x removal eff%	Regener resid. time, min	Regener temp °F	NG #/hr	NG/S mol ratio	Total sulfur in regenerated sorbent,%	Absorber pressure drop, in WC	Back pulsing
8-5	NG	107.5	0.75	747	1529	95.5	94.6	na	na	120	850	0.4	1.15	1.65	0.85	
8-1	NG	109.4	0.75	750	2246	86.8	79.4	499	95.7	120	850	0.6	1.15	2.01	1	
8-3	Coal	109.6	0.75	747	2087	77.1	86.9	512	95.4	120	850	0.6	1.16	1.68	5.06	no
8-1A	NG	109.3	0.75	787	2273	85.7	77.1	na	na	120	850	0.6	1.15	2.06	0.91	
9-1	NG	108.7	0.75	747	2259	84.8	85.1	na	na	180	850	0.6	1.15	1.76	0.85	
9-2	NG	108.8	1	747	2291	92.6	94.5	528	93.7	180	850	0.6	1.14	1.51	0.92	
9-8	coal	108.4	1	766	2048	92.2	95.9	574	93.9	180	850	0.6	1.14	1.36	0.9	constant
9-5	coal	111.3	1.5	747	2042	97.6	97.3	516	94	180	854	0.8	1.33	1.5	0.75	constant
9-9	coal	107.6	1.5	762	2985	93.2	95.8	588	87.9	180	850	0.8	0.92	1.45	1.05	constant
9-10	coal	110	0.75	791	3004	72.6	78.3	524	94.3	180	850	0.8	0.92	1.33	1.36	constant
9-7	NG	100	0.75	747	2430	86.6	86.5	496	88.5	180	850	0.6	0.93	1.8	0.93	
10-1	NG	108.8	0.75	747	2246	86.4	85	na	na	180	850	0.6	1.16	na	1.07	
10-3	NG	109	0.75	747	2255	84.8	89.6	na	na	180	850	0.41	0.68	1.5	1.25	
10-4	NG	108.9	0.75	741	2240	87.1	91.9	na	na	120	850	0.41	0.68	1.37	1.63	
10-5	NG	108.8	0.75	739	2283	83.1	88.2	na	na	180	800	0.6	1.15	1.55	1.50	
10-7	NG	108.8	0.75	734	2242	82.0	84.5	na	na	60	850	0.41	0.68	1.8	1.81	
10-8A	coal	108.9	0.75	747	2051	86.5	na	635	96.7	180	850	0.6	1.14	NA	1.51	constant
10-8C	coal	108.9	0.75	738	2077	84.5	na	na	na	180	850	0.6	1.16	NA	1.79	constant

Table 5

MBCUO-06	PARAMETER	TAG	E/U	1	2	3	4
COMBUSTOR FILE				COMB075	COMB076	COMB077	COMB078
	COMB AIR	FY-1	#/HR	475.7	475.8	461.3	488.2
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	22.10	0.00
	NATURAL GAS	FY-20	#/HR	23.55	23.53	4.17	23.36
	COAL	WKT-26	#/HR	0.00	0.00	33.93	0.00
	FEEDER WT	WT-26	LBS	0.00	0.00	39.04	38.04
	EXCESS AIR	BY-X	%XSA	20.04	20.16	22.27	24.20
	HEAT INPUT	BTU	BTU/HR	619039	618580	602656	617811
	FLUE GAS (M)	FY-15	#/HR	534.9	538.6	547.6	541.1
	FURNACE O2	AT-O2-0	%	3.81	3.86	3.49	5.06
	FURNACE P	PT-5	H2O	-0.97	-1.00	-1.01	-1.02
	COMB AIR P	PT-1	PSIG	4.89	4.77	4.70	4.61
	MOTIVE AIR P	PT-3	PSIG	95.50	96.24	96.06	94.88
	NATURAL GAS P	PT-20	PSIG	4.16	4.15	4.67	4.14
	FLUE GAS P	PT-15	-H2O	5.42	5.88	5.79	6.00
	COOL H2O P	PT-25	PSIG	154.29	154.52	153.70	154.25
	THEOR AIR	BY-X	#THEOAIR	396.29	395.97	395.65	393.13
	FURNACE CO2	AT-CO2-0	PERCENT	9.69	9.50	14.38	8.92
	FURNACE CO	AT-CO-0	PPM	11.50	11.61	138.43	25.75
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	79.97	0.00
	FLUE GAS (V)	FY-15	SCFM	114.7	115.6	117.4	116.0
ABSORBER FILE				ABS089	ABS090	ABS091	ABS092
	INLET SO2	AT-SO2-1	PPM	1529	2246	2087	2273
	INLET NOX	AT-NOx-1	PPM	192	499	512	189
	INLET O2	AT-O2-1	PERCENT	4.30	4.35	3.43	4.59
	OUTLET SO2	AT-SO2-2	PPM	67	293	473	320
	OUTLET NOX	AT-NOx-2	PPM	181	21	23	179
	OUTLET O2	AT-O2-2	PERCENT	4.49	4.60	3.64	4.83
	NO SPIKE	FT-101	#/HR	0.00	0.08	0.00	0.00
	SO2 SPIKE	FT-102	#/HR	0.90	1.53	0.10	1.56
	NH3 SPIKE	FT-103	#/HR	0.000	0.123	0.139	0.000
	BED DP	PDT-19	H2O	0.86	1.00	5.06	0.91
	FLUE GAS (M)	FY-17	#/HR	501.7	510.4	511.3	509.8
	INLET P	PT-17	-H2O	7.19	7.48	7.55	7.77
	SCREEN DP	PDT-21	H2O	0.64	0.77	4.67	0.69
	GAS INLET	TE-18	DEG F	747	750	747	787
	GAS OUTLET	TE-21	DEG F	671	682	680	697
	SORB IN	TE-390	DEG F	695	722	682	698
	SORB OUT	TE-391	DEG F	659	671	675	668
	SO2 REMOVAL	SO2REF	PERCENT	95.5	86.9	77.1	85.7
	NOX REMOVAL	NOXREF	PERCENT	5.0	95.7	95.4	4.0
	FLUE GAS (V)	FY-17	SCFM	107.5	109.4	109.6	109.3
REGENERATOR FILE				REG089	REG090	REG091	REG092
	QUICK REP O2	AT-O2-4A	PERCENT	0.11	0.01	0.00	0.00
	REGEN SO2	AT-SO2-4	PERCENT	40.82	51.55	38.05	39.19
	REGEN CH4	AT-CH4-4	PERCENT	0.13	17.73	19.98	21.23
	REGEN CO2	AT-CO2-4	PERCENT	46.20	36.30	33.69	37.38
	REGEN H2S	AT-H2S-4	PERCENT	1.17	1.12	0.06	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.47	0.11	0.01	0.00
	NATURAL GAS	FY-300	#/HR	0.40	0.60	0.60	0.60
	NITROGEN	FY-310	#/HR	0.00	0.00	0.00	0.00
	REGEN P	PT-380	H2O	2.00	11.66	1.14	4.76
	SORB LEVEL	LT-380	INCHES	16.80	16.18	16.95	15.69
	TSORB (2")	TE-381	DEG F	852	816	822	791
	TSORB (17")	TE-382	DEG F	877	820	831	806
	TSORB (32")	TE-383	DEG F	955	919	953	963
	TSORB (47")	TE-384	DEG F	945	902	947	964
	TGAS(EXIT)	TE-385	DEG F	953	903	955	965
	T OFFGAS	TE-386	DEG F	244	247	248	252
	T COND EX	TE-387	DEG F	83	78	79	89
	T INC EX	TE-200	DEG F	607	580	589	634
	INCIN O2	AT-O2-5	PERCENT	18.84	18.61	18.77	18.55
	INCIN SO2	AT-SO2-5	PPM	587	566	629	562
FLUID BED HEATER FILE				FBH089	FBH090	FBH091	FBH092
	TSORB(12")	TE-373	DEG F	1030	1079	1080	1061
	NATURAL GAS	FY-55	#/HR	4.74	4.78	4.81	4.64
	AHTR AIR (M)	FY-30	#/HR	294.8	282.4	286.1	284.1
	FBH VEL	SY-30	FT/SEC	6.00	6.00	6.00	6.00
	FBH O2	AT-O2-3	PERCENT	16.26	15.75	16.01	16.04
	TAHTR OUT	TE-370	DEG F	1080	1113	1106	1101
	T PLENUM	TE-372	DEG F	992	1024	1024	1023
	TSORB(24")	TE-374	DEG F	955	992	980	986
	TVENT	TE-375	DEG F	775	826	822	837
	THUM OUT	TE-376	DEG F	500	500	501	500
	FBH PRES	PT-376	H2O	14.25	14.60	20.00	19.65
	BED DP	PDT-376	H2O	18.28	12.73	13.06	13.04
	PLENUM DP	PDT-377	H2O	10.48	12.73	14.46	15.39
	FBH NOX	AT-NOx-3	PPM	14.30	13.15	15.03	16.05
	FBH SO2	AT-SO2-3	PPM	0.00	0.00	1.45	19.34
	AHTR AIR (V)	FY-30	SCFM	64.5	61.8	62.6	62.2
	REG NGAS (V)	FY-300S	SCFM	0.15	0.22	0.22	0.22
	REG N2 (V)	FY-310S	SCFM	0.00	0.00	0.00	0.00
FLUID BED COOLER FILE				FBC089	FBC090	FBC091	FBC092
	FBC AIR VEL	SY-360	FT/SEC	7.00	6.98	7.02	6.97
	AIR (M)	FY-360	#/HR	218.8	213.5	219.2	214.4
	T PLENUM	TE-362	DEG F	1005	1025	1025	1025
	T LOWER	TE-363	DEG F	949	966	955	967
	BED DP	PDT-365	H2O	18.82	19.59	16.88	14.16
	PLENUM DP	PDT-367	H2O	6.29	6.36	6.16	6.30
	FBC PRES	PT-366	H2O	2.00	2.03	2.08	2.02
	T UPPER	TE-364	DEG F	950	969	956	970
	T HEATER	TE-361	DEG F	514	535	530	530
	T AIR	TE-360	DEG F	78	80	76	76
	AIR PRES	PT-360	PSIG	2.87	2.81	2.93	2.98
	AIR DP	FT-360	H2O	0.62	0.60	0.61	0.59
	INLET SO2(ADJ)	SO2REF	PPM	1594	2348	2068	2409
	OUTLET SO2(ADJ)	SO2REF	PPM	71	311	475	348
	INLET NOX(ADJ)	NOXREF	PPM	201	522	507	201
	OUTLET NOX(ADJ)	NOXREF	PPM	190	22	23	193
	AIR (V)	FY-360	SCFM	47.9	46.7	48.0	46.9
	TR HOPPER	SSCYCLES	CYCLE	1196	1547	1871	2032
TEMPERATURE FILE				TEMP075	TEMP076	TEMP077	TEMP078
	COMB AIR T	TE-1	DEG F	74	79	78	74
	CO AIR HTR T	TE-3	DEG F	526	525	540	540
	MOT AIR T	TE-6	DEG F	64	66	60	69
	FUR REFR T	TE-4	DEG F	1991	2013	2200	2028
	FURN EXIT T	TE-9	DEG F	1140	1130	1316	1444
	TOT FGAS T	TE-15	DEG F	860	863	862	909
	ABS FGAS T	TE-18	DEG F	750	752	749	790
	HUM EXIT T	TE-27	DEG F	385	385	385	385
	BGHS TOP T	TE-29	DEG F	354	355	357	360
	BGHS BOT T	TE-30	DEG F	353	353	353	358
	ABS Z1 T	TIC-85	DEG F	750	750	751	749
	ABS Z2 T	TIC-88	DEG F	750	750	750	750
	ABS Z3 T	TIC-91	DEG F	750	750	750	750
	ABS Z4 T	TIC-94	DEG F	750	750	750	749
	ABS Z5 T	TIC-97	DEG F	750	751	751	750
	CW SUP T	TE-42	DEG F	119	121	119	114
	CW FUR EXT	TE-43	DEG F	146	148	146	137
	CW FGC EXT	TE-44	DEG F	89	91	89	106
	NAT GAS T	TE-20	DEG F	75	74	73	64

Table 6

MBCUO-09	PARAMETER	TAG	E/U	1	2	3	4	5	6	7
COMBUSTOR FILE				COMB061	COMB062	COMB063	COMB065	COMB066	COMB067	COMB068
	COMB AIR	FY-1	#/HR	486.2	486.3	473.9	474.0	459.4	469.7	452.6
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	21.63	21.32	21.79	21.85	0.00
	NATURAL GAS	FY-20	#/HR	24.18	24.18	4.17	4.17	4.17	4.17	22.81
	COAL	WKT-26	#/HR	0.00	0.00	35.36	35.10	34.91	34.69	0.00
	FEEDER WT	WT-26	LBS	0.00	0.00	39.12	39.40	38.95	38.95	38.64
	EXCESS AIR	BY-X	%XSA	19.98	19.98	21.18	22.03	21.51	22.15	19.98
	HEAT INPUT	BTU	BTU/HR	638442	638890	620531	617215	614334	603143	583072
	FLUE GAS (M)	FY-15	#/HR	536.5	536.3	546.0	558.1	542.9	561.9	498.2
	FURNACE O2	AT-O2-0	%	3.74	3.87	3.24	3.38	4.19	3.98	3.93
	FURNACE P	PT-5	H2O	-1.01	-1.00	-0.97	-1.01	-1.05	-1.02	-1.01
	COMB AIR P	PT-1	PSIG	4.67	4.50	4.13	3.84	4.09	4.36	4.52
	MOTIVE AIR P	PT-3	PSIG	96.16	96.34	97.82	96.00	99.54	96.11	96.07
	NATURAL GAS P	PT-20	PSIG	4.86	4.88	5.42	5.43	5.45	5.46	4.89
	FLUE GAS P	PT-15	-H20	5.73	5.67	5.77	5.73	5.81	6.09	5.10
	COOL H2O P	PT-25	PSIG	155.18	155.42	154.34	155.26	154.65	153.82	154.33
	THEOR AIR	BY-X	#THEOAIR	405.23	405.30	409.19	406.24	404.66	402.65	377.27
	FURNACE CO2	AT-CO2-0	PERCENT	9.77	9.92	14.37	6.93	14.50	15.37	10.41
	FURNACE CO	AT-CO-0	PPM	11.81	9.75	54.79	117.63	361.88	137.79	26.53
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	80.24	79.85	80.79	80.05	0.00
	FLUE GAS (V)	FY-15	SCFM	114.8	114.8	117.0	119.6	116.4	118.3	106.8
ABSORBER FILE				ABS098	ABS099	ABS100	ABS102	ABS103	ABS104	ABS105
	INLET SO2	AT-SO2-1	PPM	2259	2291	2048	2042	2985	3004	2430
	INLET NOX	AT-NOx-1	PPM	200	528	574	516	588	524	496
	INLET O2	AT-O2-1	PERCENT	3.78	3.98	3.15	3.53	3.58	3.65	4.00
	OUTLET SO2	AT-SO2-2	PPM	326	162	153	47	204	811	324
	OUTLET NOX	AT-NOx-2	PPM	187	32	33	30	71	30	57
	OUTLET O2	AT-O2-2	PERCENT	4.66	4.35	3.99	4.27	3.52	3.78	4.05
	NO SPIKE	FT-101	#/HR	0.00	0.08	0.00	0.00	0.02	0.00	0.09
	SO2 SPIKE	FT-102	#/HR	1.47	1.50	0.07	0.09	1.02	1.06	1.57
	NH3 SPIKE	FT-103	#/HR	0.000	0.124	0.156	0.135	0.146	0.146	0.106
	BED DP	PDT-19	H2O	0.85	0.92	0.90	0.75	1.06	1.36	0.93
	FLUE GAS (M)	FY-17	#/HR	506.8	507.7	505.8	519.2	502.0	513.3	466.5
	INLET P	PT-17	-H2O	7.48	7.39	7.60	7.53	7.46	7.94	6.43
	SCREEN DP	PDT-21	H2O	0.66	0.74	0.44	0.41	0.85	1.12	0.88
	GAS INLET	TE-18	DEG F	747	747	766	747	762	791	747
	GAS OUTLET	TE-21	DEG F	685	690	695	703	715	706	686
	SORB IN	TE-390	DEG F	717	721	729	790	785	724	763
	SORB OUT	TE-391	DEG F	678	696	725	740	766	633	686
	SO2 REMOVAL	SO2REF	PERCENT	84.8	92.8	92.2	97.6	93.2	72.8	86.6
	NOX REMOVAL	NOXREF	PERCENT	1.5	93.7	93.9	94.0	87.9	94.3	88.5
	FLUE GAS (V)	FY-17	SCFM	108.7	108.8	108.4	111.3	107.6	110.0	100.0
REGENERATOR FILE				REG098	REG099	REG100	REG102	REG103	REG104	REG105
	QUICK REP O2	AT-O2-4A	PERCENT	0.02	0.00	0.28	0.03	0.75	0.04	0.01
	REGEN SO2	AT-SO2-4	PERCENT	39.83	43.04	39.52	32.35	41.59	40.25	42.27
	REGEN CH4	AT-CH4-4	PERCENT	9.26	6.06	6.86	5.91	5.89	22.15	14.84
	REGEN CO2	AT-CO2-4	PERCENT	44.08	42.98	44.23	43.16	41.47	34.81	38.35
	REGEN H2S	AT-H2S-4	PERCENT	0.19	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.26	0.02	0.31	0.37	0.14	0.03	0.02
	NATURAL GAS	FY-300	#/HR	0.60	0.60	0.60	0.80	0.80	0.80	0.60
	NITROGEN	FY-310	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN P	PT-380	H2O	1.56	1.31	0.30	2.40	0.24	2.65	3.26
	SORB LEVEL	LT-380	INCHES	24.70	40.10	40.26	50.20	50.02	25.44	25.14
	TSORB (2")	TE-381	DEG F	842	871	850	851	826	852	858
	TSORB (17")	TE-382	DEG F	839	860	849	861	833	899	893
	TSORB (32")	TE-383	DEG F	857	825	849	836	839	843	846
	TSORB (47")	TE-384	DEG F	960	839	848	861	855	968	969
	TGAS(EXIT)	TE-385	DEG F	998	857	865	866	890	1010	1010
	T OFFGAS	TE-386	DEG F	262	247	242	264	256	252	245
	T COND EX	TE-387	DEG F	34	33	34	35	34	33	34
	T INC EX	TE-200	DEG F	555	566	571	507	539	593	614
	INCIN O2	AT-O2-5	PERCENT	18.96	19.16	18.87	18.92	19.15	18.88	18.75
	INCIN SO2	AT-SO2-5	PPM	731	720	554	604	815	586	495
FLUID BED HEATER FILE				FBH098	FBH099	FBH100	FBH102	FBH103	FBH104	FBH105
	TSORB(12")	TE-373	DEG F	1200	870	870	895	895	894	870
	NATURAL GAS	FY-55	#/HR	6.07	6.16	6.10	6.31	6.34	6.20	6.07
	AHTR AIR (M)	FY-30	#/HR	325.1	449.3	448.6	436.1	435.5	442.3	449.1
	FBH VEL	SY-30	FT/SEC	7.50	8.21	8.20	8.20	8.20	8.20	8.20
	FBH O2	AT-O2-3	PERCENT	15.19	17.09	16.88	16.42	16.53	16.67	16.78
	TAHTR OUT	TE-370	DEG F	1222	886	907	929	961	943	901
	T PLENUM	TE-372	DEG F	1146	929	922	968	968	942	919
	TSORB(24")	TE-374	DEG F	1170	862	863	887	886	886	861
	TVENT	TE-375	DEG F	937	801	801	819	818	820	801
	THUM OUT	TE-376	DEG F	500	500	500	500	500	500	500
	FBH PRES	PT-376	H2O	6.62	10.13	3.64	9.11	9.58	9.62	10.01
	BED DP	PDT-376	H2O	17.27	10.20	10.70	10.37	10.90	10.50	10.38
	PLENUM DP	PDT-377	H2O	17.40	11.24	11.26	11.14	11.24	11.29	11.35
	FBH NOX	AT-NOx-3	PPM	18.41	9.39	10.71	10.40	11.37	11.62	9.47
	FBH SO2	AT-SO2-3	PPM	3.32	0.00	0.00	0.00	9.67	12.63	0.00
	AHTR AIR (V)	FY-30	SCFM	71.1	98.3	98.2	95.4	95.3	96.8	98.3
	REG NGAS (V)	FY-300S	SCFM	0.22	0.22	0.22	0.29	0.29	0.29	0.22
	REG N2 (V)	FY-310S	SCFM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FLUID BED COOLER FILE				FBC098	FBC099	FBC100	FBC102	FBC103	FBC104	FBC105
	FBC AIR VEL	SY-360	FT/SEC	7.53	8.52	8.50	8.48	8.50	8.51	8.48
	AIR (M)	FY-360	#/HR	225.3	262.5	258.6	257.0	257.8	257.5	255.4
	T PLENUM	TE-362	DEG F	1046	1000	1025	1000	1000	1032	1040
	T LOWER	TE-363	DEG F	991	968	975	969	966	989	991
	BED DP	PDT-365	H2O	19.22	15.86	13.87	17.02	10.54	14.15	16.35
	PLENUM DP	PDT-367	H2O	5.67	6.49	6.88	6.18	7.22	6.64	6.51
	FBC PRES	PT-366	H2O	1.99	2.24	2.24	2.19	2.13	2.37	2.26
	T UPPER	TE-364	DEG F	992	960	977	971	968	991	992
	T HEATER	TE-361	DEG F	549	515	530	519	512	531	534
	T AIR	TE-360	DEG F	85	84	87	96	83	76	70
	AIR PRES	PT-360	PSIG	2.68	2.59	2.63	2.45	2.62	2.77	2.78
	AIR DP	FT-360	H2O	0.68	0.92	0.89	0.91	0.89	0.86	0.84
	INLET SO2(ADJ)	SO2REF	PPM	2282	2341	1998	2031	2981	3017	2487
	OUTLET SO2(ADJ)	SO2REF	PPM	346	169	157	49	204	818	332
	INLET NOX(ADJ)	NOXREF	PPM	202	539	555	514	595	528	509
	OUTLET NOX(ADJ)	NOXREF	PPM	199	34	34	31	71	30	59
	AIR (V)	FY-360	SCFM	49.3	57.4	56.6	56.2	56.4	56.3	55.9
	TR HOPPER	SSCYCLES	CYCLE	638	1081	420	858	1274	1499	1674
TEMPERATURE FILE				TEMP061	TEMP062	TEMP063	TEMP065	TEMP066	TEMP067	TEMP068
	COMB AIR T	TE-1	DEG F	81	80	87	98	81	73	67
	CO AIR HTR T	TE-3	DEG F	550	550	520	520	520	450	450
	MOT AIR T	TE-6	DEG F	74	75	73	78	73	67	69
	FUR REFR T	TE-4	DEG F	2063	2067	2283	2288	2307	2308	2220
	FURN EXIT T	TE-9	DEG F	1253	1249	1334	1303	1416	1456	1397
	TOT FGAS T	TE-15	DEG F	855	854	860	852	874	909	860
	ABS FGAS T	TE-18	DEG F	750	750	769	750	765	794	750
	HUM EXIT T	TE-27	DEG F	385	385	385	385	385	385	385
	BGHS TOP T	TE-29	DEG F	355	353	356	358	356	357	354
	BGHS BOT T	TE-30	DEG F	358	356	355	357	355	356	356
	ABS Z1 T	TIC-85	DEG F	750	750	749	750	749	750	750
	ABS Z2 T	TIC-88	DEG F	750	750	750	750	749	750	750
	ABS Z3 T	TIC-91	DEG F	750	750	749	750	749	750	750
	ABS Z4 T	TIC-94	DEG F	750	750	749	750	750	750	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750	750	750	750
	CW SUP T	TE-42	DEG F	135	138	124	133	122	116	111
	CW FUR EXT	TE-43	DEG F	162	165	154	163	150	143	137
	CW FGC EXT	TE-44	DEG F	93	83	95	84	83	80	85
	NAT GAS T	TE-20	DEG F	80	77	80	83	79	76	81

Table 7

MBCUO-10	PARAMETER	TAG	E/U	1	2	3	4	5	6	7
COMBUSTOR FILE				COMB091	COMB092	COMB093	COMB094	COMB095	COMB096	COMB097
	COMB AIR	FY-1	#/HR	503.1	502.9	503.0	502.9	503.1	435.5	437.5
	MOTIVE AIR	FY-3	#/HR	0.00	0.00	0.00	0.00	0.00	21.81	21.92
	NATURAL GAS	FY-20	#/HR	25.01	25.01	25.01	25.01	25.01	3.13	3.13
	COAL	WKT-25	#/HR	0.00	0.00	0.00	0.00	0.00	33.70	33.91
	FEEDER WT	WT-25	LBS	0.00	0.00	0.00	0.00	0.00	39.70	39.23
	EXCESS AIR	BY-X	%XSA	20.00	19.99	20.01	19.95	20.01	21.92	21.81
	HEAT INPUT	BTU	BTU/HR	670117	673220	673226	673386	673334	583790	581163
	FLUE GAS (M)	FY-15	#/HR	565.9	565.5	566.3	566.2	566.2	521.8	520.2
	FURNACE O2	AT-O2-0	%	3.77	3.81	3.91	3.80	3.86	3.95	3.01
	FURNACE P	PT-5	H2O	-0.99	-0.96	-0.99	-1.02	-0.98	-1.03	-1.08
	COMB AIR P	PT-1	PSIG	4.69	4.69	4.65	4.76	5.02	4.69	4.62
	MOTIVE AIR P	PT-3	PSIG	96.04	96.03	99.22	98.06	96.66	96.65	97.93
	NATURAL GAS P	PT-20	PSIG	4.86	4.89	4.93	4.89	4.92	5.51	5.52
	FLUE GAS P	PT-15	-H2O	6.34	6.27	6.13	6.19	6.09	4.64	5.40
	COOL H2O P	PT-25	PSIG	113.45	113.36	112.79	112.84	112.00	110.63	112.78
	THEOR AIR	BY-X	#THEOAIR	419.24	419.15	419.15	419.22	419.21	375.35	377.26
	FURNACE CO2	AT-CO2-0	PERCENT	10.03	10.06	9.91	9.84	9.80	14.37	14.47
	FURNACE CO	AT-CO-0	PPM	10.52	11.27	11.76	12.33	9.89	22.74	89.01
	MOTIVE AIR V	SY-3	FT/SEC	0.00	0.00	0.00	0.00	0.00	80.01	80.18
	FLUE GAS (V)	FY-15	SCFM	121.3	121.2	121.4	121.4	121.4	111.9	111.8
ABSORBER FILE				ABS108	ABS109	ABS110	ABS111	ABS112	ABS113	ABS114
	INLET SO2	AT-SO2-1	PPM	2246	2255	2240	2283	2242	2051	2077
	INLET NOX	AT-NOx-1	PPM	225	254	222	207	209	635	525
	INLET O2	AT-O2-1	PERCENT	4.29	4.31	4.39	4.34	4.46	3.90	3.58
	OUTLET SO2	AT-SO2-2	PPM	300	339	286	382	400	274	314
	OUTLET NOX	AT-NOx-2	PPM	218	252	218	205	213	21	498
	OUTLET O2	AT-O2-2	PERCENT	4.55	4.48	4.53	4.47	4.61	4.03	3.96
	NO SPIKE	FT-101	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SO2 SPIKE	FT-102	#/HR	1.56	1.58	1.57	1.60	1.57	0.07	0.07
	NH3 SPIKE	FT-103	#/HR	0.000	0.000	0.001	0.001	0.001	0.166	0.000
	BED DP	PDT-19	H2O	1.07	1.26	1.63	1.50	1.81	1.51	1.79
	FLUE GAS (M)	FY-17	#/HR	507.6	506.4	506.2	507.7	507.7	506.0	508.2
	INLET P	PT-17	-H2O	8.02	7.97	7.83	7.90	7.77	6.28	7.18
	SCREEN DP	PDT-21	H2O	0.87	0.99	1.96	1.21	1.50	0.72	0.91
	GAS INLET	TE-18	DEG F	747	747	741	739	734	747	738
	GAS OUTLET	TE-21	DEG F	683	681	680	678	675	686	670
	SORB IN	TE-390	DEG F	714	721	714	717	716	712	748
	SORB OUT	TE-391	DEG F	674	675	673	673	668	690	603
	SO2 REMOVAL	SO2REF	PERCENT	86.4	84.8	87.1	83.1	82.0	86.5	84.5
	NOX REMOVAL	NOXREF	PERCENT	2.0	0.4	1.0	0.4	0.0	96.7	3.1
	FLUE GAS (V)	FY-17	SCFM	108.8	109.0	108.9	108.8	108.8	108.9	108.9
REGENERATOR FILE				REG108	REG109	REG110	REG111	REG112	REG113	REG114
	QUICK REP O2	AT-O2-4A	PERCENT	0.03	0.34	0.02	0.00	0.00	0.01	0.04
	REGEN SO2	AT-SO2-4	PERCENT	42.38	45.54	46.78	39.73	46.96	39.60	40.00
	REGEN CH4	AT-CH4-4	PERCENT	14.26	6.34	5.34	24.61	13.71	17.22	19.06
	REGEN CO2	AT-CO2-4	PERCENT	41.62	44.03	40.06	36.76	38.39	37.83	37.21
	REGEN H2S	AT-H2S-4	PERCENT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN O2	AT-O2-4B	PERCENT	0.27	0.35	0.17	0.12	0.20	0.25	0.10
	NATURAL GAS	FY-300	#/HR	0.60	0.41	0.41	0.60	0.41	0.60	0.60
	NITROGEN	FY-310	#/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	REGEN P	PT-380	H2O	2.79	3.04	3.40	2.91	1.77	3.27	2.38
	SORB LEVEL	LT-380	INCHES	24.98	25.15	16.58	24.92	7.86	24.12	25.18
	TSORB (2")	TE-381	DEG F	857	845	854	779	858	844	866
	TSORB (17")	TE-382	DEG F	845	845	861	792	881	836	842
	TSORB (32")	TE-383	DEG F	864	873	945	820	964	858	865
	TSORB (47")	TE-384	DEG F	909	909	932	871	940	948	949
	TGAS(EXIT)	TE-385	DEG F	927	929	941	884	928	974	975
	T OFFGAS	TE-386	DEG F	276	276	279	278	273	276	275
	T COND EX	TE-387	DEG F	33	33	33	32	32	33	32
	T INC EX	TE-200	DEG F	622	633	599	569	582	617	594
	INCIN O2	AT-O2-5	PERCENT	18.82	18.87	19.12	19.10	18.88	18.71	18.49
	INCIN SO2	AT-SO2-5	PPM	483	501	385	351	409	375	220
FLUID BED HEATER FILE				FBH108	FBH109	FBH110	FBH111	FBH112	FBH113	FBH114
	TSORB(12")	TE-373	DEG F	975	975	975	880	900	924	925
	NATURAL GAS	FY-55	#/HR	6.64	6.65	6.72	6.19	6.44	6.43	6.41
	AHTR AIR (M)	FY-30	#/HR	415.2	419.0	422.0	450.6	451.0	441.8	436.1
	FBH VEL	SY-30	FT/SEC	8.28	8.29	8.29	8.30	8.31	8.29	8.30
	FBH O2	AT-O2-3	PERCENT	16.02	16.05	16.16	16.78	16.66	16.45	16.17
	TAHTR OUT	TE-370	DEG F	1047	1045	1021	954	987	1008	1013
	T PLENUM	TE-372	DEG F	1049	1048	1050	935	960	981	984
	TSORB(24")	TE-374	DEG F	967	965	967	872	892	917	917
	TVENT	TE-375	DEG F	892	892	893	810	827	849	848
	THUM OUT	TE-376	DEG F	500	500	499	500	500	500	500
	FBH PRES	PT-376	H2O	9.87	9.54	9.45	10.02	10.28	9.49	8.93
	BED DP	PDT-376	H2O	10.09	10.44	9.77	10.06	9.69	9.02	9.74
	PLENUM DP	PDT-377	H2O	10.95	11.06	11.06	11.26	11.35	11.21	11.22
	FBH NOX	AT-NOx-3	PPM	16.45	16.04	17.34	12.46	13.04	11.98	12.66
	FBH SO2	AT-SO2-3	PPM	0.01	0.93	7.35	0.00	2.36	5.66	3.75
	AHTR AIR (V)	FY-30	SCFM	90.8	91.7	92.3	98.7	98.7	96.7	95.4
	REG NGAS (V)	FY-300S	SCFM	0.22	0.15	0.15	0.22	0.15	0.22	0.22
	REG N2 (V)	FY-310S	SCFM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FLUID BED COOLER FILE				FBC108	FBC109	FBC110	FBC111	FBC112	FBC113	FBC114
	FBC AIR VEL	SY-360	FT/SEC	8.51	8.50	8.51	8.48	8.48	8.49	8.46
	AIR (M)	FY-360	#/HR	251.6	252.8	260.0	255.0	258.0	257.9	253.5
	T PLENUM	TE-362	DEG F	1071	1076	1013	1075	1079	1069	1065
	T LOWER	TE-363	DEG F	1004	1006	978	994	999	998	1002
	BED DP	PDT-365	H2O	12.81	10.23	14.71	14.07	9.67	11.68	11.21
	PLENUM DP	PDT-367	H2O	6.80	7.46	7.16	7.23	7.41	7.23	6.93
	FBC PRES	PT-366	H2O	2.16	2.27	2.21	2.30	2.55	2.49	2.23
	T UPPER	TE-364	DEG F	1006	1007	980	996	1001	1000	1003
	T HEATER	TE-361	DEG F	555	558	455	558	558	557	546
	T AIR	TE-360	DEG F	80	79	92	82	74	82	78
	AIR PRES	PT-360	PSIG	2.72	2.72	2.58	2.63	2.77	2.70	2.68
	AIR DP	FT-360	H2O	0.84	0.84	0.91	0.86	0.85	0.87	0.84
	INLET SO2(ADJ)	SO2REF	PPM	2340	2351	2346	2384	2360	2087	2078
	OUTLET SO2(ADJ)	SO2REF	PPM	318	357	303	402	425	281	322
	INLET NOX(ADJ)	NOXREF	PPM	234	264	233	216	220	648	518
	OUTLET NOX(ADJ)	NOXREF	PPM	230	265	230	216	226	21	509
	AIR (V)	FY-360	SCFM	55.1	55.3	56.9	55.8	56.4	56.4	55.5
	TR HOPPER	SSCYCLES	CYCLE	619	848	1178	1450	1721	1931	2113
TEMPERATURE FILE				TEMP091	TEMP092	TEMP093	TEMP094	TEMP095	TEMP096	TEMP097
	COMB AIR T	TE-1	DEG F	73	72	68	75	67	74	75
	CO AIR HTR T	TE-3	DEG F	625	650	650	650	650	650	599
	MOT AIR T	TE-6	DEG F	65	67	58	60	56	67	66
	FUR REFR T	TE-4	DEG F	2245	2233	2262	2267	2264	2809	2581
	FURN EXIT T	TE-9	DEG F	1030	1048	1019	1015	1012	1087	1157
	TOT FGAS T	TE-15	DEG F	855	855	851	849	845	857	844
	ABS FGAS T	TE-18	DEG F	750	749	743	742	737	750	741
	HUM EXIT T	TE-27	DEG F	385	385	385	385	385	385	385
	BGHS TOP T	TE-29	DEG F	359	358	358	357	356	354	353
	BGHS BOT T	TE-30	DEG F	359	360	358	358	357	355	356
	ABS Z1 T	TIC-85	DEG F	747	750	750	750	750	750	750
	ABS Z2 T	TIC-88	DEG F	751	750	750	750	750	750	749
	ABS Z3 T	TIC-91	DEG F	750	750	750	750	750	750	750
	ABS Z4 T	TIC-94	DEG F	750	750	750	750	750	750	750
	ABS Z5 T	TIC-97	DEG F	750	750	750	750	750	750	748
	CW SUP T	TE-42	DEG F	101	101	109	111	106	107	106
	CW FUR EXT	TE-43	DEG F	147	149	160	162	157	158	160
	CW FGC EXT	TE-44	DEG F	89	91	76	78	76	88	87
	NAT GAS T	TE-20	DEG F	80	82	68	71	67	79	77

Table 8. Gas Phase and Solid Phase Sulfur Recoveries

Test number & condition	Regener-ation temp, °F	Residence time, min	Absorber outlet hopper	Regenerator outlet hopper	Sorbent feed rate lb/hr	SO_2 removed (gas phase) #mol/hr	SO_2 regen-erated (gas ph) #mol/hr	Error%	SO_2 removed (solid phase) #mol/hr	Error%
MBCUO-8										
TC #5 1/21/96	850	120	3.27	1.65	45				0.0228	
TC #1 1/23/96	850	120	3.67	2.01	45	0.029	0.031	+6.9%	0.0233	-19.7%
TC #3 1/25/96	850	120	3.24	1.68	45	0.0246	0.0228	-7.3%	0.0219	-10.8%
TC #1A 1/26/96	850	120	3.97	2.06	45	0.0286	0.0345	+20.8%	0.0269	-5.9%
MBCUO-9										
TC #1 2/23/96	850	180	3.75	1.76	45	0.0277	0.0272	-3.7%	0.0280	+1.1%
TC #2 2/24/96	850	180	3.13	1.51	60	0.0307	0.0290	-5.5%	0.0304	-0.98%
TC #8 2/26/96	850	180	3.07	1.36	60	0.0295	0.0271	-8.1%	0.0321	+8.8%
TC #5 2/27/96	850	180	3.16	1.51	90	0.0316	0.0311	-1.9%	0.0464	+46.8%
TC #9 2/28/96	850	180	3.98	1.45	90	0.0433	0.0419	-4.3%	0.0712	+64.3%
TC #10 2/29/96	850	180	3.14	1.33	45	0.0347	0.0359	+3.5%	0.0254	-26.8%
TC #7 3/01/96	850	180	3.51	na	45	0.0278	0.0279	+0.4%	na	na
MBCUO-10										
TC #1 3/22/96	850	180	na	na	45	0.0279	0.0257	-7.9%	na	na
TC #3 3/23/96	850	180	3.36	1.5	45	0.0274	0.0227	-17.2%	0.0262	-4.4%
TC #4 3/24/96	850	120	3.34	1.37	45	0.0281	0.0242	-13.9%	0.0277	-1.4%
TC #5 3/25/96	800	180	3.5	1.55	45	0.0272	0.0257	-5.5%	0.0274	+0.07%
TC #7 3/27/96	850	60	3.51	1.8	45	0.0264	0.0241	-8.6%	0.0240	-9.1%
TC #8A 3/27/96	850	180			45	0.0281	0.0251	-10.7%	na	na

Table 9. Effect of Screen Design and Sorbent on Performance*

Parameter	MBCUO-6-9	MBCUO-7-1	MBCUO-8-1	MBCUO-9-1	MBCUO-10-1
Sorbent	1/16" Grace		1/8" Alcoa		
Screen	Square Weave & Perforated Plate	Bar			
Bed Dimensions H(ft) x W (ft) x D (in)	8 x 1 x 5				
SO_2 Removal (%)	94	93	87	85	86
Total Absorber Pressure Drop (in H_2O)	2.5	1.4	1.0	0.8	1.1
Major Observations	Screen plugged with ash/sorbent fines during coal burn	New screen reduces plugging with lower pressure drop and no apparent change in SO_2 removal	Larger sorbent yields lower pressure drop but also lower SO_2 removal	Absorber parametric study	Regenerator parametric study

* Natural Gas Fire; 110 SCFM Flue Gas Flow; 750°F Absorber; 2250 ppm SO_2 Spike; 0.75 lb/min Sorbent Flow; 850°F Regenerator; 2 or 3 Hr Regenerator Residence Time; Twice Stiochiometric Requirement of Methane fed to Regenerator.

Table 10. Absorber Pressure Drop Information in MBCuO-09.

Test Condition	MBCuO-9-1		MBCuO-9-2		MBCuO-9-8																	
Fuel	Natural Gas		Natural Gas		Coal																	
Pulsing Status	Profile		Profile		Pre-Pulse		Post-Pulse		Pre-Pulse		Post-Pulse		Pre-Pulse		Post-Pulse		Pre-Pulse		Post-Pulse		Profile	
Pressure Drop (in H_2O)	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total
Top	0.7	0.8	0.7	0.9	4.8	5.0	0.7	1.1	3.9	4.3	0.9	1.2	2.9	3.3	1.2	1.7	3.9	4.5	0.6	1.1	0.6	1.0
Middle	0.6	0.8	0.7	0.9	4.1	4.8	1.1	1.6	3.1	4.3	0.9	1.5	2.2	3.5	0.8	1.4	2.2	3.9	0.3	1.1	0.3	0.9
Bottom	0.6	0.8	0.7	0.9	2.6	4.8	0.5	1.3	1.9	4.4	0.6	1.5	1.3	3.6	0.7	1.9	1.5	4.3	0.4	1.1	0.7	0.9

Test Condition	MBCuO-9-5								MBCuO-9-9									
Fuel	Coal								Coal									
Pulsing Status	Pre-Pulse		Post-Pulse		Post-Pulse		Profile		Pre-Pulse		Post-Pulse		Pre-Pulse		Post-Pulse		Profile	
Pressure Drop (in H_2O)	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total
Top	3.4	3.7	1.2	1.6	0.6	0.9	0.4	0.8	3.2	3.4	1.7	2.0	3.3	3.5	0.9	1.2	0.9	1.2
Middle	3.3	3.8	1.0	1.5	0.5	0.8	0.5	0.9	3.0	3.4	1.6	2.0	3.0	3.5	0.8	1.0	1.0	1.2
Bottom	2.7	3.7	1.0	1.4	0.6	0.8	0.5	0.9	2.2	3.4	1.5	2.1	2.4	3.4	0.8	1.1	0.9	1.0

Test Condition	MBCuO-9-10										MBCuO-9-7 (1a)	
Fuel	Coal										Natural Gas	
Pulsing Status	Pre-Pulse		Pre-Pulse		Post-Pulse		Pre-Pulse		Profile		Profile	
Pressure Drop (in H_2O)	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total	Rear Screen	Total
Top	2.4	2.9	4.6	5.1	3.5	3.7	3.8	4.1	1.0	1.3	0.7	0.9
Middle	2.0	3.1	3.5	4.9	1.4	2.0	3.2	4.2	1.0	1.3	0.8	0.9
Bottom	1.7	3.0	2.7	4.7	3.0	4.1	3.3	4.2	1.3	2.5	0.9	1.2

Note: Rear screen pressure taps located at three bed heights (top, middle, and bottom). Pressure taps for total pressure drop (front screen, sorbent bed, plus rear screen) are located at one bed height (near bottom). Total pressure drop is simultaneously recorded while rear screen pressure drop is sequentially profiled at three bed heights.

Table 11. Total Dust Distribution for Select Coal-Fired Test Conditions

Equipment		MBCUO-7-5&6			MBCUO-8-3			MBCUO-9-10			MBCUO-10-8a		
		Mass (lb)	% Fraction		Mass (lb)	% Fraction		Mass (lb)	% Fraction		Mass (lb)	% Fraction	
			Total	Fly		Total	Fly		Total	Fly		Total	Fly
Furnace Ashpot	Total Dust	32.9	35.9	-	14.2	30.2	-	10.0	24.2	-	NA	-	-
Absorber Inlet Ashpot	Total Dust	6.8	7.4	11.6	1.6	3.4	4.9	8.4	20.3	26.8	2.8	NA	14.1
Absorber Outlet Ashpot	Total Dust	7.0	7.6	11.9	4.6	9.8	14.0	2.6	6.3	8.3	4.0	NA	20.2
Furnace Baghouse	Total Dust	8.8	9.6	15.0	7.0	14.9	21.3	9.2	22.2	29.3	3.8	NA	19.2
Fluid-Bed Heater Baghouse	Total Dust	36.2	39.5	61.6	19.6	41.7	59.8	11.2	27.1	35.7	9.2	NA	46.5
Total	Total Dust	91.7			47.0			41.4			19.8		

Table 12. Material Balances for Total Dust During MBCUO Tests

Equipment		MBCUO-7			MBCUO-8			MBCUO-9			MBCUO-10		
		Mass (lb)	% Fraction		Mass (lb)	% Fraction		Mass (lb)	% Fraction		Mass (lb)	% Fraction	
			Total	Fly		Total	Fly		Total	Fly		Total	Fly
Furnace Ashpot	Total Dust	73.7	33.6	-	15.0	11.5	-	84.0	21.2	-	17.2	7.9	-
Absorber Inlet Ashpot	Total Dust	11.2	5.1	7.7	7.7	5.9	6.6	42.0	10.6	13.4	21.9	10.1	11.0
Absorber Outlet Ashpot	Total Dust	14.1	6.4	9.7	22.4	17.1	19.3	67.0	16.9	21.4	29.8	13.7	14.9
Furnace Baghouse	Total Dust	35.3	16.1	24.2	11.1	8.5	9.6	47.8	12.1	15.3	18.7	8.6	9.4
Fluid-Bed Heater Baghouse	Total Dust	81.4	37.1	55.9	57.2	43.7	49.3	118	29.8	37.8	99.8	46.0	50.0
Fluid-Bed Cooler Cyclone	Total Dust	4.0	1.8	2.7	17.6	13.4	15.2	37.6	9.5	12.0	29.4	13.6	14.7
Total	Total Dust	219.3			131			396.4			216.8		
Coal burnt		1905			808			2841			1147		
Expected ash		191			80.8			284			115		
Sorbent makeup		67.3			43.1			239			265.7		
Dust balance (expected ash+sorbent makeup-total dust)		39	17.8		-7.1	-5.4		127	32.0		164	75.6	

Table 13. Ash and Sorbent Balances for MBCUO-8

Test Condition	Cu%	# dust	# sorbent	# ash
#5, NG 1/21/96				
AB-IN-POT	0.6*	0.2	0.02	0.18
AB-OUT-POT	6.4*	2.6	2.52	0.08
BH	na	0	0	0
FBH	3.1*	5.4	2.54	2.86
#1, NG 1/23/96				
AB-IN-POT	0.6*	0.1	0.01	0.09
AB-OUT-POT	6.4*	3.8	3.68	0.12
BH	0.3*	0.6	0.03	0.57
FBH	3.1*	12.	5.64	6.36
#3, COAL 1/25/96				
AB-IN-POT	0.6	1.6	0.15	1.45
AB-OUT-POT	6.9	4.6	4.6	0
BH	0.3	7	0.32	6.68
FBH	4.8*	19.6	14.25	5.35
#1A, NG 1/26/96				
AB-IN-POT	0.6	1.2	0.12	1.08
AB-OUT-POT	6.4	3	2.91	0.09
BH	0.3	2.6	0.13	2.47
FBH	3.1	11	5.17	5.83
POST				
AB-IN-POT	1	4.6	0.7	3.9
AB-OUT-POT	6.4	2.0	1.94	0.06
BH	0.3	0.5	0.023	0.477
FBH	4.8	2.8	2.04	0.76
FBC	8.2	17.6	17.6	0
Ash collected in furnace pot				15.
Total wt, lbs		102.8	64.39	53.41
Coal fired	808 lbs			ash 80.8 lbs
Sorbent attrited	43.05			

Dust enclosure = (102.8 + 15) - (43.05 + 80.8) = -6.05 lbs (shortage)
Sorbent balance = 64.39 - 43.05 = 21.34 lbs (surplus) = 49.57% of sorbent makeup
Coal ash balance = 53.41 - 80.8 = -27.39 lbs (shortage) = -33.9% of expected coal ash including slag on furnace wall.
Note: If dust copper analysis is 6.6% or greater, the dust is considered as 100% sorbent.
* Indicates default copper analysis value.

Table 14. Ash and Sorbent Balances for MBCUO-9

Test Condition	Cu%	# dust	# sorbent	# ash
#1, NG 2/23/96				
AB-IN-POT	3.9	3.2	1.89	1.31
AB-OUT-POT	7.	26.2	26.2	0
BH	4.2	3.2	2.04	1.16
FBH	5.7	18.2	15.72	2.48
#2, NG 2/24/96				
AB-IN-POT	5.9	0.4	0.36	0.04
AB-OUT-POT	6.7	11.2	11.2	0
BH	1.2	0.2	0.04	0.16
FBH	6.3	26.6	25.39	1.21
#8, COAL 2/26/96	(921 Lbs fired)			
AB-IN-POT	3.4	11.8	6.08	5.72
AB-OUT-POT	6.8	13.6	13.6	0
BH	0.5	11.8	0.89	10.91
FBH	6.4	17.0	16.48	0.52
#5, COAL 2/27/96	(744 Lbs fired)			
AB-IN-POT	0.5	2.4	0.18	2.22
AB-OUT-POT	5.9	6.2	5.54	0.36
BH	0.3	7.6	0.35	7.25
FBH	4.5	18	12.27	5.73
#9, COAL 2/28/96	(549 Lbs fired)			
AB-IN-POT	0.2	13	0.39	12.61
AB-OUT-POT	7	4.4	4.4	0
BH	0.2	11.4	0.35	11.05
FBH	3.4	16.2	8.35	7.85
#10, COAL 2/29/96	(549 Lbs fired)			
AB-IN-POT	0.1	8.4	0.13	8.27
AB-OUT-POT	4.5	2.4	1.64	0.76
BH	0.2	9.2	0.28	8.92
FBH	3.7	11.2	6.28	4.92

Table 14 continuation #7, NG 3/1/96				
AB-IN-POT	0.2	1.0	0.03	0.97
AB-OUT-POT	5.2	1.2	0.95	0.25
BH	0.2	3.8	0.12	3.68
FBH	4	6.8	4.12	2.68
POST 3/4/96				
AB-IN-POT	0.2	1.8	0.05	1.75
AB-OUT-POT	5.4	1.6	1.3	0.3
BH	0.2	0.6	0.02	0.58
FBH	4.7	4.0	2.85	1.15
FBC	8.0	37.6	37.6	0
TOTAL ASH IN FURNACE POT				84.0
TOTAL WT		312.2	207	189
COAL FIRED	2841 lbs			COAL ASH EXPECTED = 284 lbs
SORBENT ATTRITED	239 lbs			

TOTAL DUST UNACCOUNTED FOR = (284 + 239) - (207 + 189) = 523 - 396 = 127 Lbs

Sorbent balance = 207 - 239 = -32 lbs (shortage) = 13.4% of sorbent makeup

Coal ash balance = 189 - 284 = -95 lbs (shortage) = 33.5% of coal ash input

Note: If copper analysis on dust is 6.6% or greater it is considered as 100% sorbent dust.

Table 15. Ash and Sorbent Balances for MBCUO-10

Test Condition	Cu%	# dust	# sorbent	# ash
#1 NG 3/22/96				
AB-IN-POT	0.5*	0.5	0.038	0.46
AB-OUT-POT	5.9*	8.0	7.15	0.85
BH	0.6*	6.4	0.58	5.82
FBH	5.4*	32	26.18	5.82
#3 NG 3/23/96				
AB-IN-POT	0.5	0.6	0.045	0.555
AB-OUT-POT	5.9	3.2	2.86	0.34
BH	0.6	0.3	0.027	0.273
FBH	5.4	7.2	5.89	1.31
#4 NG 3/24/96				
AB-IN-POT		0	0	0
AB-OUT-POT	5.9	3.8	3.4	0.6
BH		0	0	0
FBH	5.8	11.2	9.84	1.36
#5 NG 3/25/96				
AB-IN-POT	0.4	0.2	0.012	0.188
AB-OUT-POT	6.2	3.6	3.38	0.22
BH	0.6	0.6	0.055	0.545
FBH	5.6	11.0	9.33	1.67
#7 NG 3/27/96				
AB-IN-POT	0.5	0.2	0.015	0.185
AB-OUT-POT	6.2	3.2	3.0	0.2
BH	0.4	0.6	0.036	0.564
FBH	5.5	10	8.33	1.67

Table 15 continuation #8A COAL 3/27				
AB-IN-POT	0.2	2.8	0.085	2.715
AB-OUT-POT	0.3	4	0.18	3.82
BH	0.3	3.8	0.17	3.63
FBH	4.9	9.2	6.83	2.37
Table 15 continuation 8C COAL 3/29				
AB-IN-POT	0.09	7.8	0.11	7.69
AB-OUT-POT	5.9	3	2.68	0.32
BH	0.9	4.4	0.6	3.8
FBH	4.8	9.6	6.98	2.62
POST				
AB-IN-POT	0.1	9.8	0.15	9.65
AB-OUT-POT	0.2	1.0	0.03	0.97
BH	0.2	2.6	0.079	2.521
FBH	8.8	9.6	9.6	0
FBC	7.2	29.4	29.4	0
Ash in furnace pot				17.2
TOTAL WT lbs		200.03	137.4	79.9
COAL FIRED	1147 lbs			coal ash expected = 115 lbs
SORBENT ATTRITED	265.73 lbs			

Total dust unaccounted for = (265.73 + 115) - (137.4 + 79.9) = 163.4 lbs

Sorbent unaccounted for = 265.73 - 137.4 = 128.33 lbs = 48.3% of sorbent

Coal ash unaccounted for = 115 - 79.9 = 35.1 lbs = 30.5% of coal ash

Note: If dust copper analysis is 6.6% or greater the dust is considered as 100% sorbent.

• Indicates default copper analysis value. The default value depends upon coal or gas fired.

Table 16. Sorbent/Ash Distribution for Select Coal-Fired Test Conditions

Equipment		MBCUO-7-5&6			MBCUO-8-3			MBCUO-9-10			MBCUO-10-8a		
		Mass (lb)	% Fraction		Mass (lb)	% Fraction		Mass (lb)	% Fraction		Mass (lb)	% Fraction	
			Total	Fly		Total	Fly		Total	Fly		Total	Fly
Furnace Ashpot	Ash				14.2	51.3	-	10	30.4	-	NA	-	-
	Total Dust	32.9	35.9	-	14.2	30.2	-	10.0	24.2	-	NA	-	-
Absorber Inlet Ashpot	Ash				1.45	5.2	10.8	8.27	25.2	36.2	2.72	21.7	21.7
	Sorbent				0.15	0.8		0.13	1.6		0.09	1.2	
	Total Dust	6.8	7.4	11.6	1.6	3.4	4.9	8.4	20.3	26.8	2.8	NA	14.1
Absorber Outlet Ashpot	Ash				-	-	-	0.76	2.3	3.3	3.82	30.5	30.5
	Sorbent				4.6	23.8		1.64	19.7		0.18	2.5	
	Total Dust	7.0	7.6	11.9	4.6	9.8	14.0	2.6	6.3	8.3	4.0	NA	20.2
Furnace Baghouse	Ash				6.68	24.1	49.6	8.92	27.1	39.0	3.63	28.9	28.9
	Sorbent				0.32	1.7		0.28	3.4		0.17	2.3	
	Total Dust	8.8	9.6	15.0	7.0	14.9	21.3	9.2	22.2	29.3	3.8	NA	19.2
Fluid-Bed Heater Baghouse	Ash				5.35	19.3	39.7	4.92	15.0	21.5	2.37	18.9	18.9
	Sorbent				14.3	73.8		6.28	75.4		6.83	93.9	
	Total Dust	36.2	39.5	61.6	19.6	41.7	59.8	11.2	27.1	35.7	9.2	NA	46.5
Total	Ash				27.7			32.9			12.5		
	Sorbent				19.3			8.33			7.3		
	Total Dust	91.7			47.0			41.4			19.8		

Table 17. Sorbent Attrition Data

Test	Sorbent		Absorber Design			Sorbent Attrited (lb)	Number of Transport Hopper Cycles	Hours of Operation	Attrition Rate	
	Type	Dia (in)	Retention Screen	Cross Section H(ft) x W(ft)	Bed Depth D(in)				(lb/hr)	(lb/hopper cycle)
MBCUO-2	SOX-3	1/16	Square Wire Mesh & Perforated Plate	8 x 1	5	46.8	2533	80	0.585	0.018
MBCUO-3						142.5	6740	208	0.686	0.021
MBCUO-4						144.4	4834	150.4	0.960	0.030
MBCUO-5	Grace					145	6153	191.4	0.758	0.024
MBCUO-6						73	5210	130	0.562	0.014
MBCUO-7			Spaced Bar with Vertical Slot			67.3	2085	122	0.552	0.032
MBCUO-8	Alcoa	1/8				43.1	1423	170	0.254	0.030
MBCUO-9						239.1	2763	221	1.082	0.087
MBCUO-10						265.7	2082	219	1.213	0.128

PROTECTED CRADA INFORMATION

Sorbent Type	Sub-strate (5/8/96)	New (5/8/96)	Used (5/8/96)	Used (5/14/96)
Bulk Density (lb/ft^3)	48.2	54.1	50.8	49.8
Regulator Pressure (psig)	12	12	12	15
Sorbent Removed to give 10 lbs. retained on 0.093 mesh (g)	53	9	1542	N/A
Begin Weight (g)	3016.4	3483.5	3179.0	3200.1
Removed After 2nd transport (g)	2.7	2.6	4.1	6.4
Removed After 4th transport (g)	2.0	3.0	5.4	11.2
Removed After 6th transport (g)	2.1	2.3	6.0	9.8
Returned After 8th transport (g)	2986.0	3433.4	3126.0	3114.5
Removed After 8th transport (g)	2.2	2.7	6.0	12.4
After Last Transport:				
0.093" > x >0.0278 " (g)	15.9	19	106.3	145.3
0.0278" > x (g)	2.7	4	8.8	16.0
Total Sorbent Fines Collected:				
x <0.0278" (g)	11.7	14.6	30.3	55.8
0.093" > x >0.0278 " (g)	15.9	19	106.3	145.3
TOTAL REMOVED (g)	27.6	33.6	136.6	201.1

Table 18. Transport Attrition Results

Table 19. Cold and Hot Attrition Results from the Fluidized-Bed Cooler

Cold	Weight (g)	Percent of Initial	Percent of FBC Collection
Sorbent at Start	18144.0		
Final Sorbent from FBC	12627.7	69.6	
Sorbent from FBC > 0.093"	9296.0	51.2	73.6
Sorbent from FBC 0.093 > x > 0.0278	3114.1	17.2	24.7
Sorbent from FBC < 0.0278	217.0	1.2	1.7
Sorbent from FBC cyclone	4378.4	24.1	

Hot	Weight (g)	Percent of Initial	Percent of FBC Collection
Sorbent at Start	18144.0		
Final Sorbent from FBC	14860.4	81.9	
Sorbent from FBC > 0.093"	12089.3	66.6	81.4
Sorbent from FBC 0.093 > x > 0.0278	2629.6	14.5	17.7
Sorbent from FBC < 0.0278	141.5	0.8	1.0
Sorbent from FBC cyclone	1732.5	9.6	

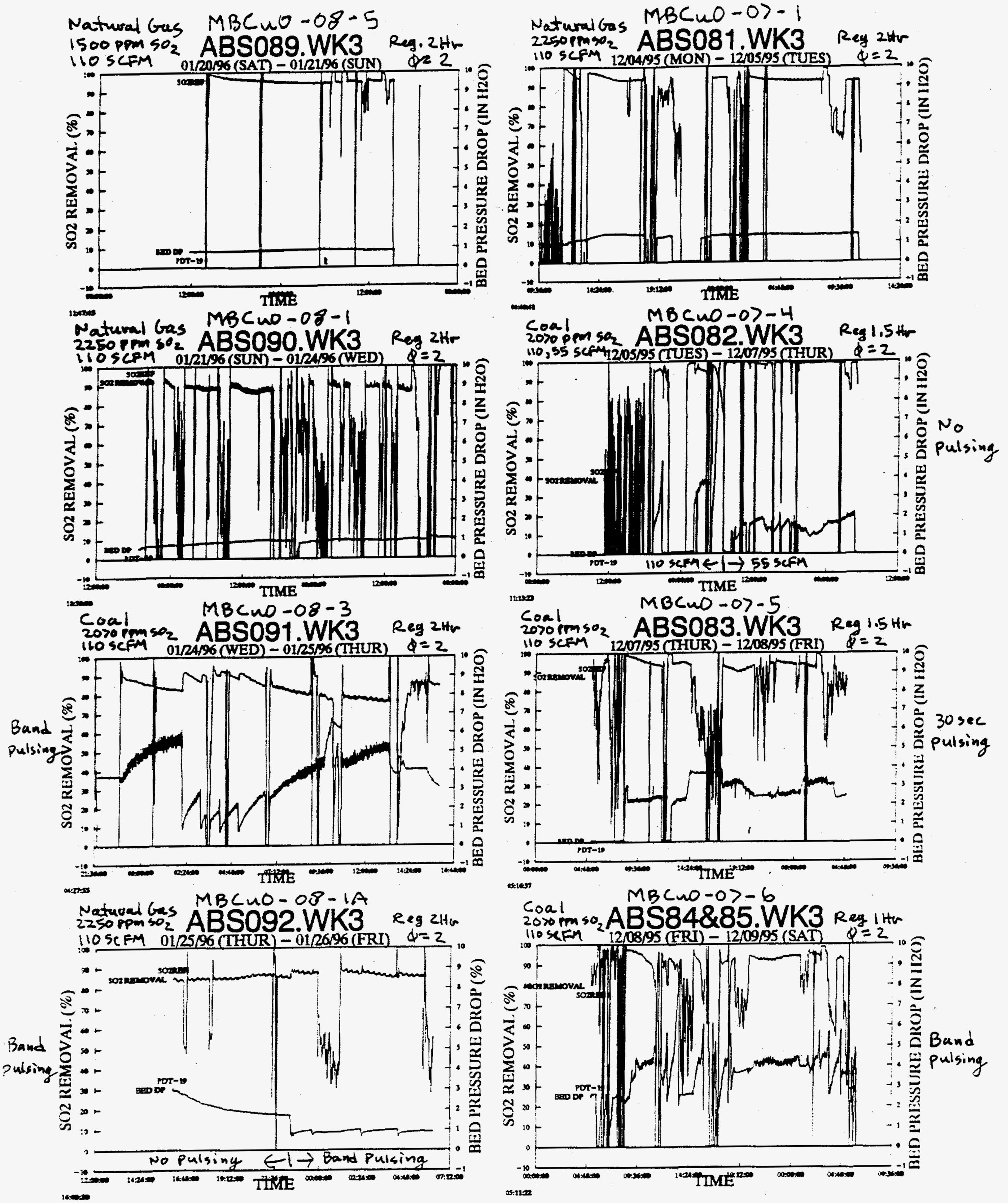

Figure 1. Pressure Drop and SO_2 Removal Versus Time for MBCUO-7 and MBCUO-8

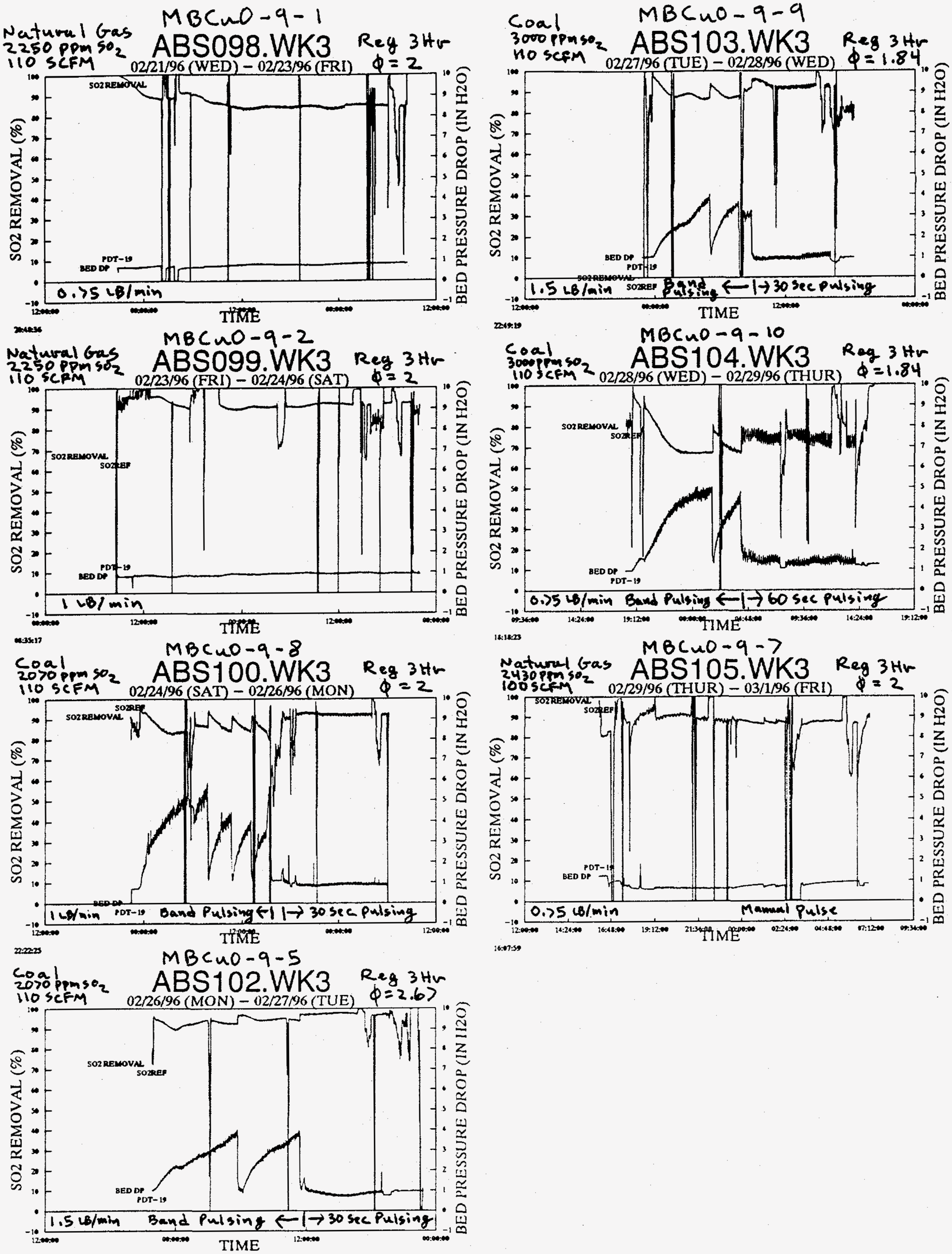

Figure 2. Pressure Drop and SO2 Removal Versus Time for MBCUO-9

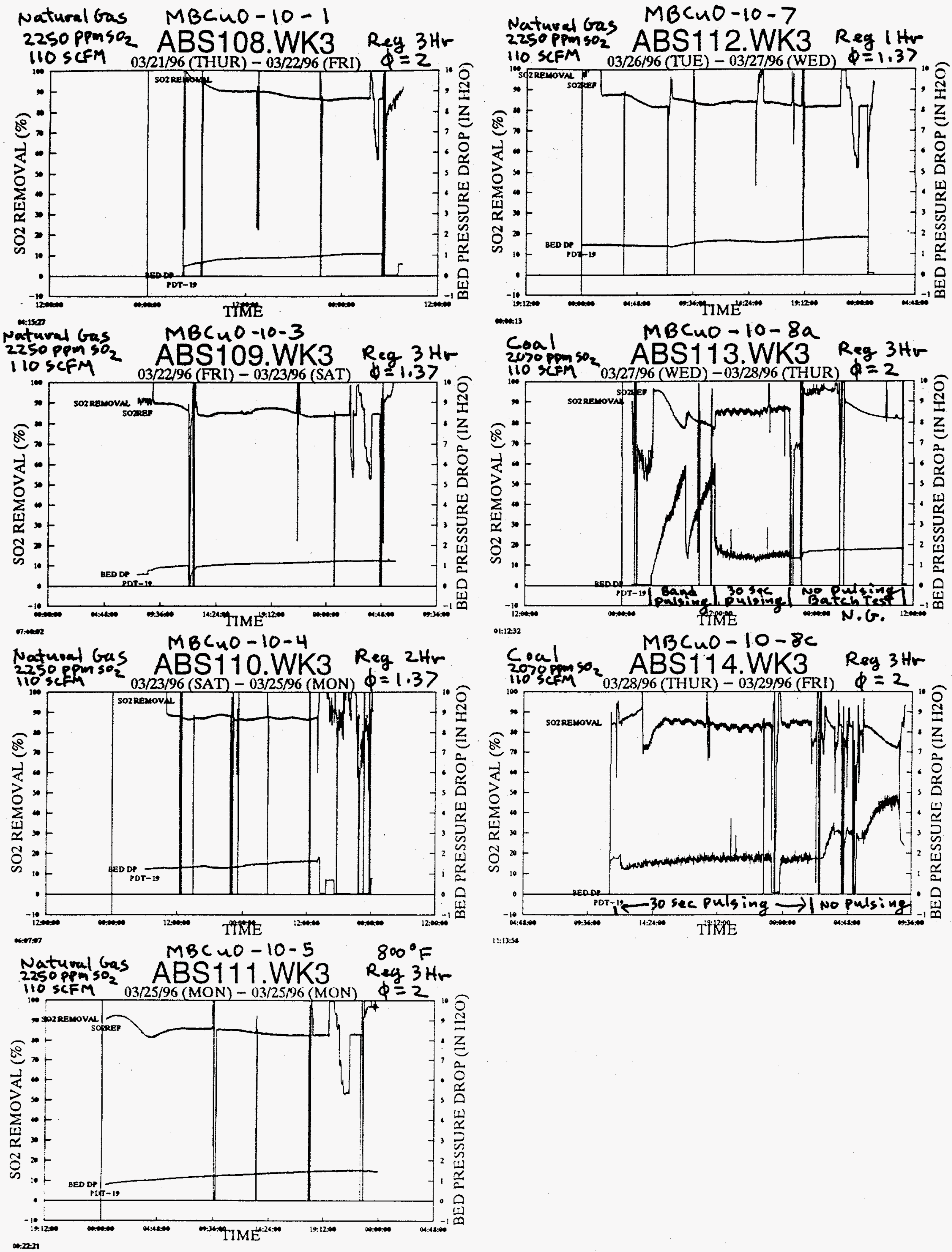

Figure 3. Pressure Drop and SO2 Removal Versus Time for MBCUO-10

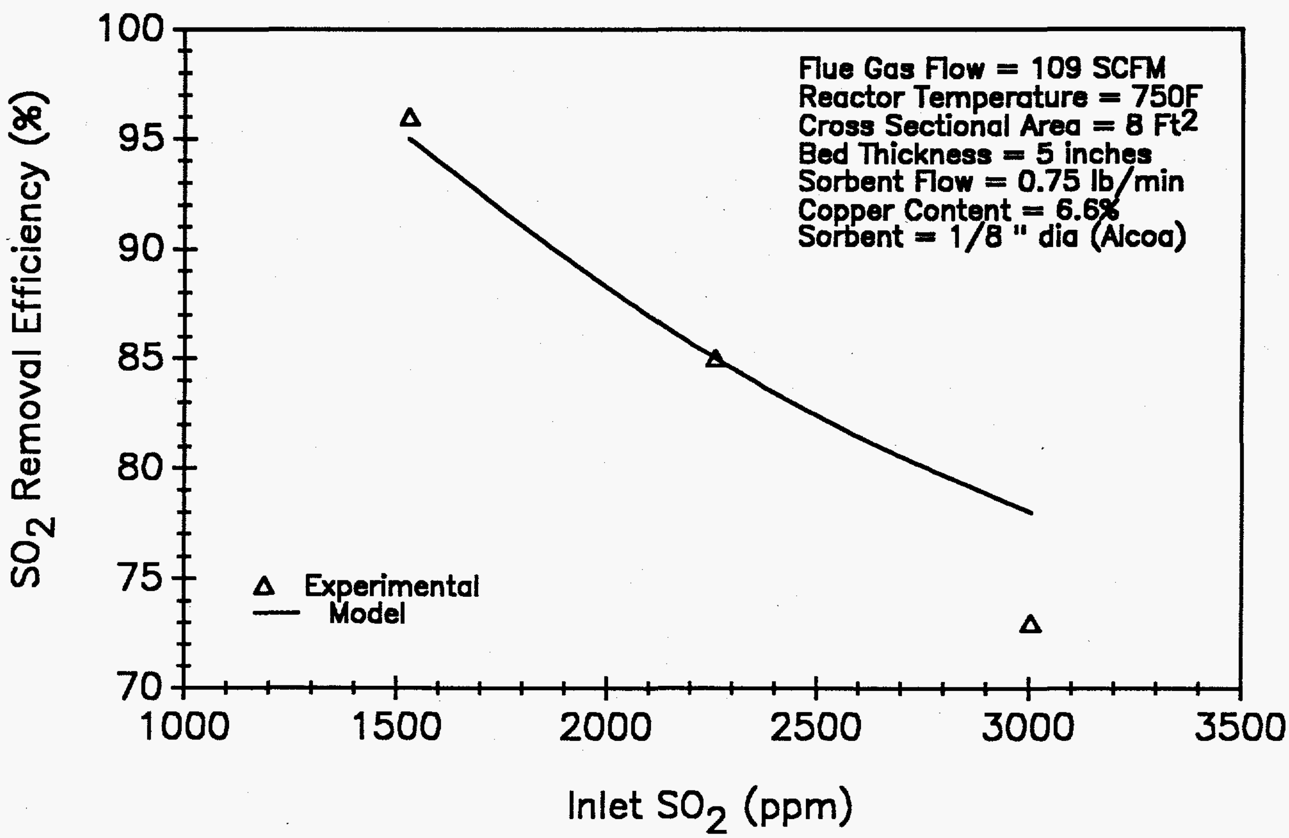

Figure 4. Effect of SO_2 Concentration on SO_2 Removal: Experimental and Calculated

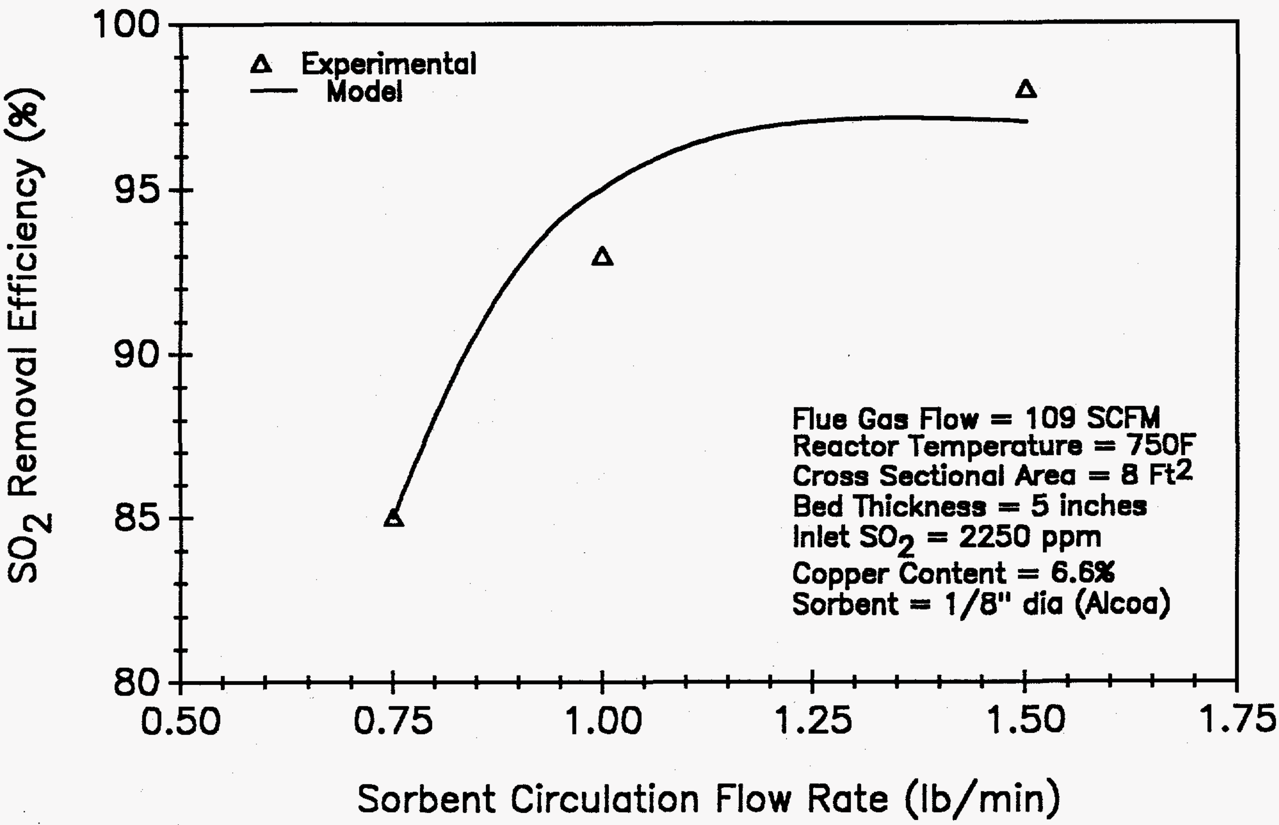

Figure 5. Effect of Sorbent Flow on SO_2 Removal: Experimental and Calculated