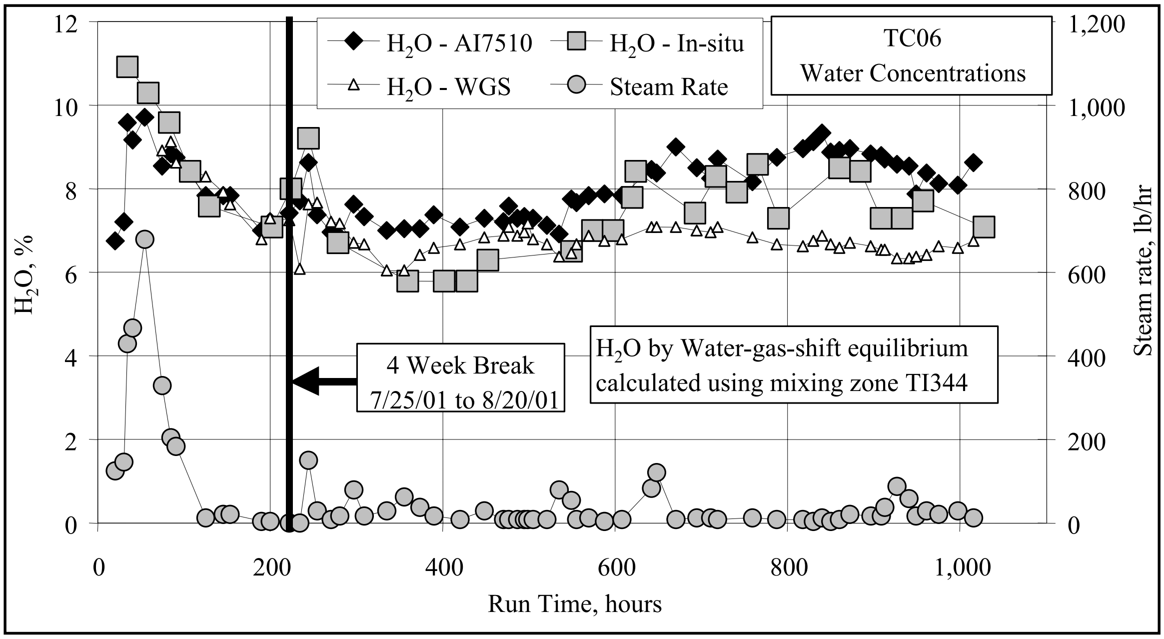

Figure 4.3-9 H_2O Data

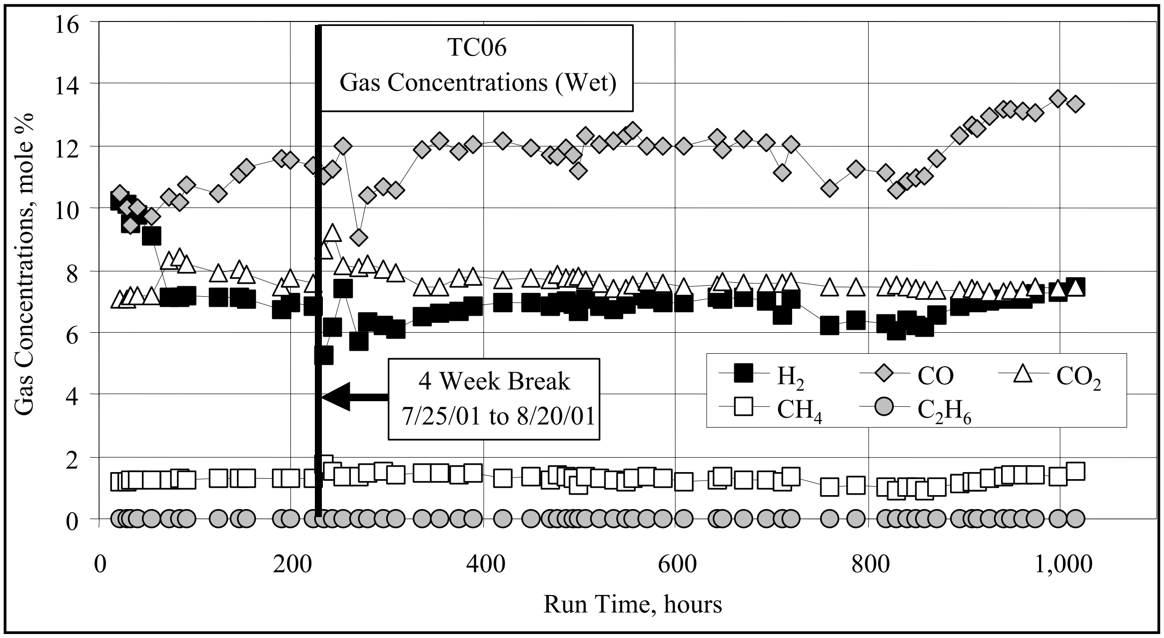

Figure 4.3-10 Wet Synthesis Gas Compositions

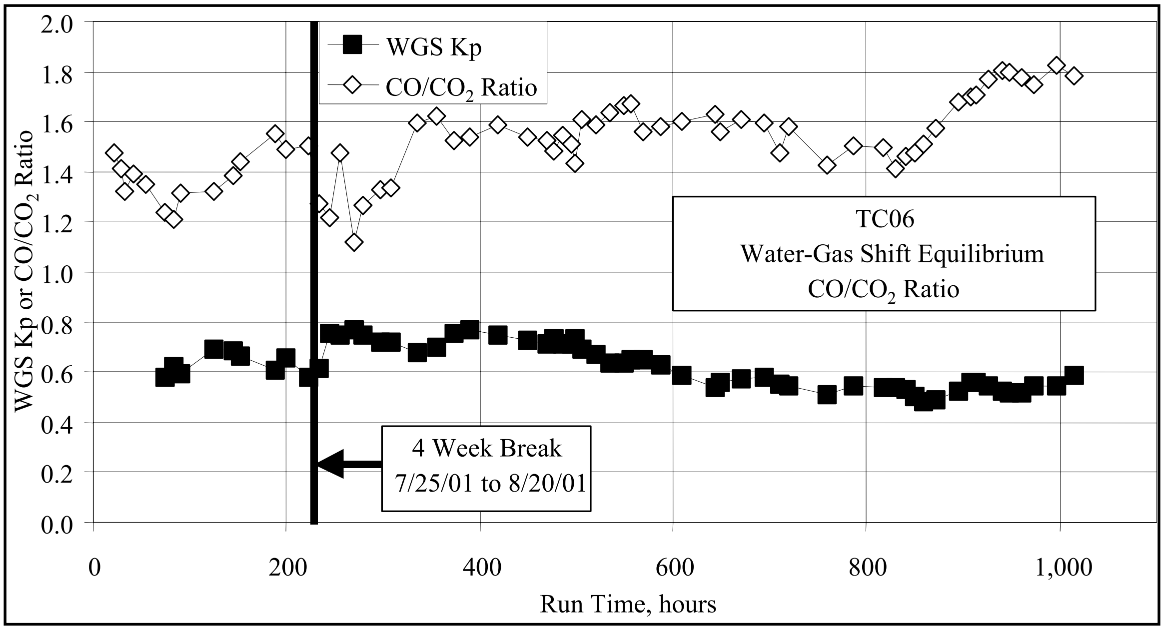

Figure 4.3-11 Water-Gas Shift Equilibrium and CO/CO$_2$ Ratio

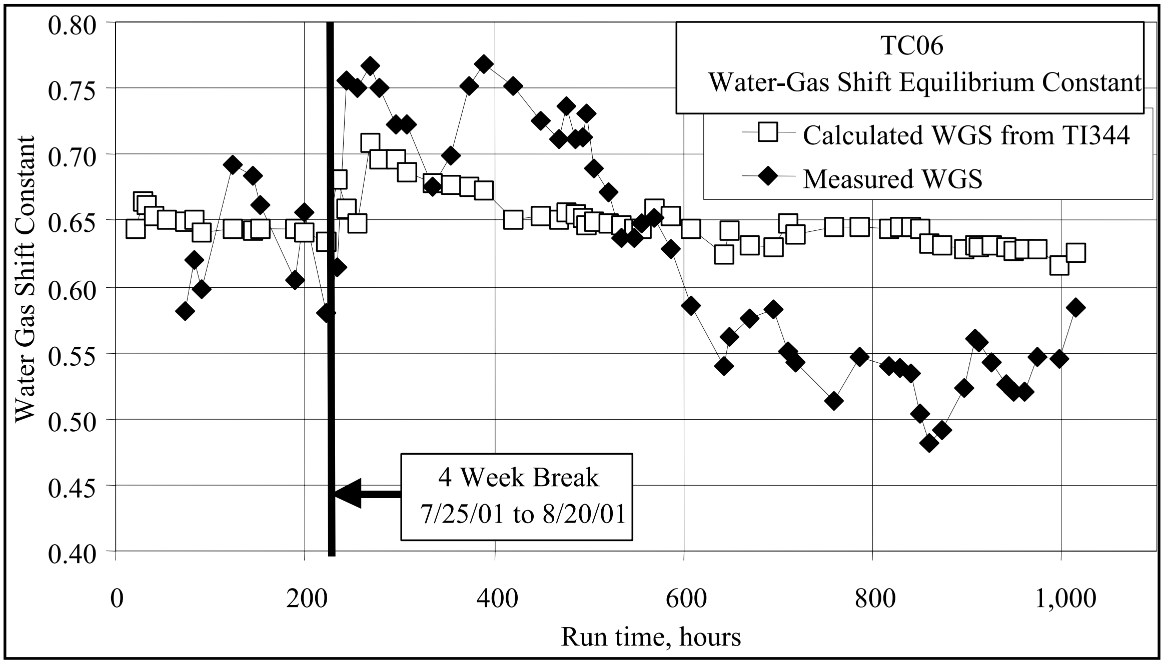

Figure 4.3-12 Water-Gas Shift Equilibrium

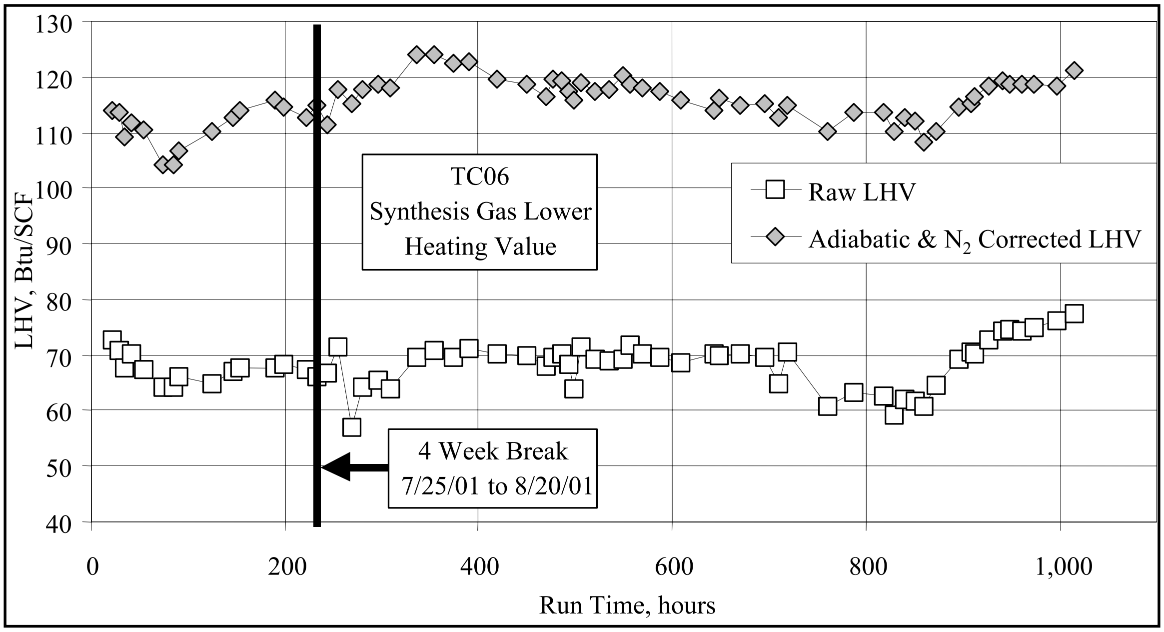

Figure 4.3-13 Synthesis Gas Lower Heating Values

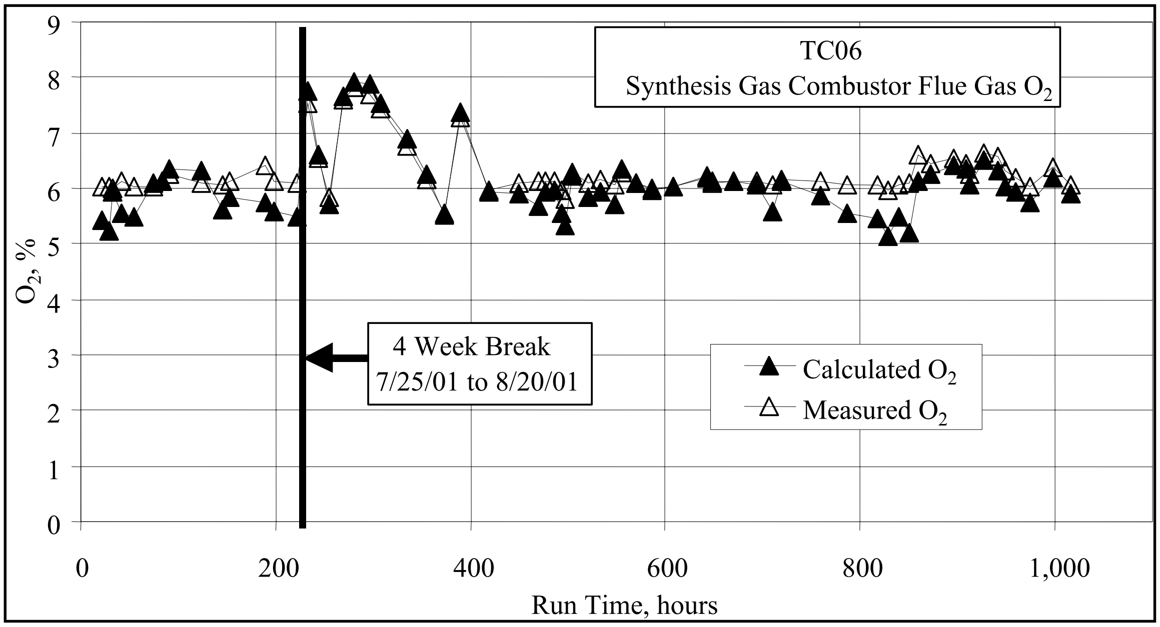

Figure 4.3-14 Synthesis Gas Combustor Outlet Oxygen

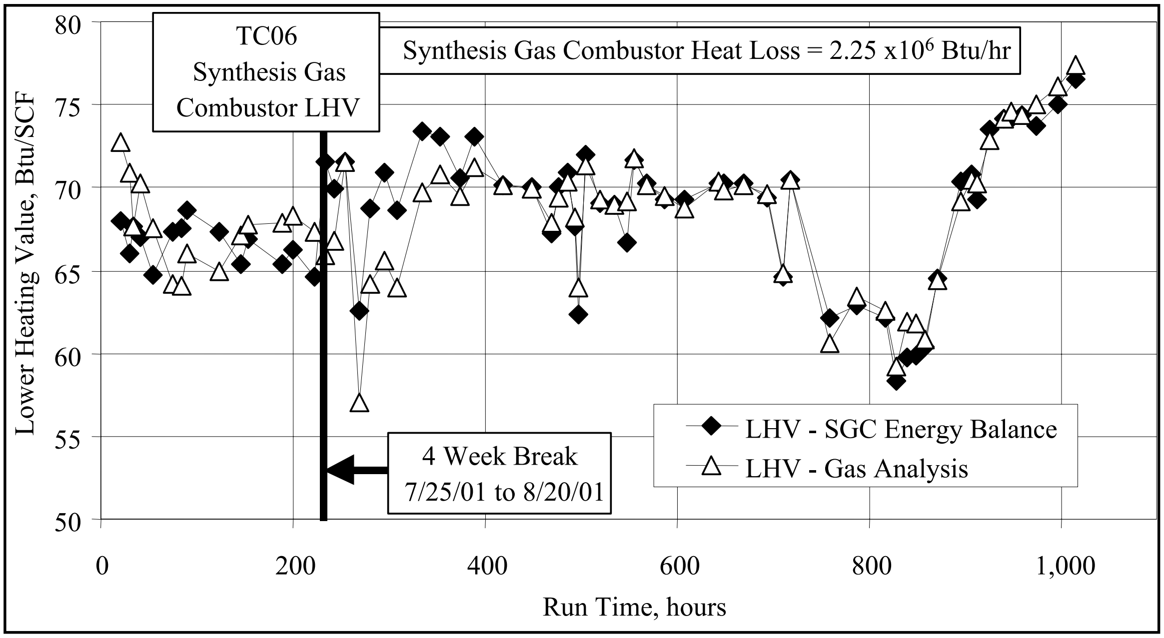

Figure 4.3-15 Synthesis Gas Combustor LHV

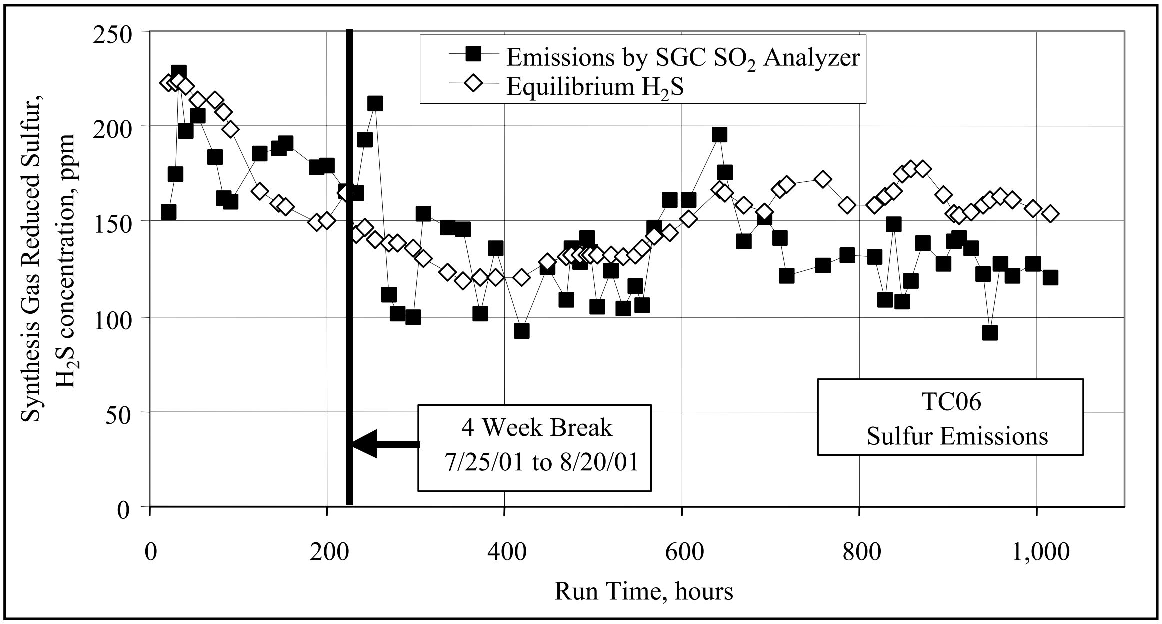

Figure 4.3-16 Sulfur Emissions

4.4 SOLIDS ANALYSES

During TC06, solid samples were collected from the fuel feed system (FD0210), the sorbent feed system (FD0220), the Transport Reactor standpipe, the standpipe spent solids transport system (FD0510), and the PCD fine solids transport system (FD0520). In situ solids samples were also collected from the PCD inlet. The sample locations are shown in Figure 4.4-1.

These solids were analyzed for chemical composition and particle size. This section will use the chemical analysis and particle size data to show:

- Chemical composition changes.
- Particle size and bulk density changes.

Table 4.4-1 shows the average coal composition for the samples analyzed during TC06. The first samples taken after both startups were excluded from the averages in Table 4.4-1 because the coal moisture level was low, probably due to air drying between testing. The coal carbon and moisture contents as sampled from FD0210 are shown in Figure 4.4-2. The average coal carbon was 57-weight percent and the average moisture was 21-weight percent.

Figure 4.4-3 shows the fuel sulfur and ash as sampled from the fuel feed system during TC06. The average values are provided in Table 4.4-1. The Powder River Basin (PRB) average coal sulfur was 0.26 percent and varied from 0.36 percent to 0.23 percent. The initial point and the first point after the 4-week shutdown are high due to the dryness of the stored coal. The coal ash was 5.2 percent and was very constant during TC06, with only a few points drifting up to 7 percent at around 740 hours.

The coal higher heating value (HHV) and lower heating value (LHV) are shown in Figure 4.4-4 and the TC06 average values are provided in Table 4.4-1. The LHV was determined from HHV by reducing the heating value to account for the coal moisture and hydrogen. The low moisture in the coal during the first several samples after the initial startup and the startup after the 4-week break caused the LHV and HHV to be higher than during the rest of the TC06. The HHV slightly increased during TC06 from 9,100 to 9,600 Btu/lb, and the LHV increased during TC06 from 8,500 to 9,000 Btu/lb.

Average values for TC06 coal moisture, carbon, hydrogen, nitrogen, sulfur, ash, oxygen, volatiles, fixed-carbon, higher heating value, lower heating value, CaO, SiO_2, Al_2O_3, Fe_2O_3, and MgO are provided in Table 4.4-1.

FD0220 was used during TC06 to feed Ohio Bucyrus limestone into the Transport Reactor. The average composition of the samples taken during TC06 are shown in Table 4.4-2 (two samples are excluded from the averages, as the samples contained a mixture of sand and limestone). The $CaCO_3$ and $MgCO_3$ contents are shown in the plot in Figure 4.4-5. The $CaCO_3$ average concentration was 76 percent, and the $MgCO_3$ average concentration was 17.7 percent. Both were constant during TC06.

The chemical compositions of the solid compounds produced by the Transport Reactor were determined using the solids chemical analysis and the following assumptions:

1. All carbon dioxide measured came from $CaCO_3$, hence moles CO_2 = moles $CaCO_3$.
2. All sulfide sulfur measured came from CaS.
3. All calcium not taken by CaS and $CaCO_3$ came from CaO.
4. All magnesium came from MgO.
5. Total carbon is measured, which is the sum of organic and inorganic (CO_2) carbon. The organic carbon is the total carbon minus the inorganic carbon (CO_2).
6. Inerts are the sum of the P_2O_5, K_2O, Na_2O, and TiO_2 concentrations.

It will be assumed that all iron in both the standpipe and PCD solids is in the form of Fe_2O_3 and not in the reduced forms of Fe_3O_4 or FeO. Thermodynamically, the mild-reducing conditions in the Transport Reactor should reduce all Fe_2O_3 to FeO. It is more likely that the iron in the standpipe and PCD solids is a mixture of Fe_2O_3 and Fe_3O_4. KBR data indicates that Fe_2O_3 is reduced to Fe_3O_4 at the temperatures and reducing conditions currently used in the Transport Reactor.

It will also be assumed that no FeS is formed in the Transport Reactor and that all the sulfur in the standpipe and PCD fines solids is as CaS. It is thermodynamically possible that some FeS is formed, but most of the captured sulfur should be in the form of CaS due to the larger amount of calcium than iron in the system.

Solids were sampled from the standpipe on a regular basis during TC06 except when the standpipe sampler was plugged between August 30 and September 5, 2001. Only one standpipe sample was taken during this period. Table 4.4-3 shows the results from the standpipe analyses. The standpipe solids are the solids that recirculate through the mixing zone, riser, and standpipe and change slowly with time, since a small amount of solids are taken out of the standpipe via FD0510 and ash gradually replaces sand. FD0510 was operated during TC06 to control the standpipe level. The flow rates for FD0510 and FD0520 solids are provided in Section 4.5.

On startup, the standpipe solids mainly contained SiO_2, with 80.4 percent at the start of TC06 and 81.7-percent SiO_2 after the 4-week break. This is because the starting bed material at both times was sand with 96.7-percent SiO_2 and 1.45-percent Al_2O_3. The standpipe did not contain sand at zero hours (July 15, 2001 01:00) and the restart (August 20, 2001, 16:00) since there were several periods of coal and coke breeze operation prior to the starting of the clock for the test. As the run progressed, the start-up sand was slowly replaced by CaO, Al_2O_3, Fe_2O_3, and other inerts until about 700 hours when the steady-state reactor solids composition was reached. This is shown in Figure 4.4-6. It took about 480 hours after the 4-week break to reach the steady-state solids composition. The SiO_2 content slowly decreases until about 700 hours. After 700 hours, the SiO_2 content was constant. Both the Al_2O_3 and the CaO increased to replace the SiO_2.

The standpipe solids data in Table 4.4-3 show that none of the volatile elements (sulfur and carbon) are present in very high concentrations after the unit is in operation for a few days. The organic carbon quickly decreases after startup to less than 0.5 percent. The high start-up carbon is probably due to the coke breeze used on startup. The heating value of the standpipe solids sampled was measured and was either 0.0 or <100 Btu/lb for all samples.

The standpipe $CaCO_3$ was at very low levels, less than 0.4 percent, indicating that there was very little inorganic carbon in the reactor. Since there was a much higher level of CaO than $CaCO_3$, all calcium that circulated in the standpipe was completely calcined. Since the standpipe calcium could come from either sorbent or fuel calcium, it is unknown whether the standpipe solids calcium was from sorbent or fuel calcium. Whatever the source, it was completely calcined. Long-term operation on a lower calcium fuel will be required to determine whether the standpipe accumulates fuel or sorbent calcium.

The sulfur level in the solids was very low, less than 0.5 percent as CaS for all of the samples. This indicates that all of the sulfur removed from the synthesis gas is removed via the PCD solids and is not accumulating in the reactor or leaving with the reactor solids. The MgO, Fe_2O_3, and other inerts contents are not included in the plot in Figure 4.4-9, but they follow the same trends as the CaO and Al_2O_3, that is, they are accumulating in the reactor as the sand is replaced by feed solids.

Figure 4.4-7 shows the organic carbon (total carbon minus CO2 carbon$_2$) for the PCD solids sampled from FD0520. The organic carbon content for every PCD fines sample analyzed is also shown in Table 4.4-4. Since FD0520 ran continuously during TC06, solid samples were taken often, with a goal of one sample every 4 hours. About half of the TC06 PCD solids that were sampled were analyzed. Solids recovered in situ during the PCD inlet particulate sampling were analyzed. The in situ carbon contents were compared with the FD0520 solids in Figure 4.4-7. The in situ organic carbon analyses shown in Figure 4.4-7 are only the ones in which both the total carbon and the CO_2 were measured. The in situ solids organic carbon analyses compared well with the FD0520 solids except for the two in situ analyses at hours 692 and 739, when the in situ samples were taken close to a period of coke breeze addition. Periods of low organic carbon content from hours 800 to 900 indicate excellent carbon conversion.

The organic carbon started the run at 46 percent, and decreased to between 25 and 32 percent (with two outliers) for the first 220 hours. After the 4-week break, the organic carbon increased to 40 percent until hour 330, and then gradually decreased to 10 percent at hour 860 as the coal rate was decreased. As the coal rate was increased at hour 900, the organic carbon increased from 10 to 42 percent by the end of TC06.

Figure 4.4-8 and Table 4.4-4 show the amounts of SiO_2 and CaO in the PCD solids as sampled from FD0520. Also, included in the plot on Figure 4.4-8, are the in situ solids concentrations for SiO_2 and CaO. The in situ samples showed good agreement with the FD0520 samples for the first 600 hours of TC06. For the last 400 hours of TC06 the in situ SiO_2 and CaO analyses were consistently lower than the FD0520 analyses. The SiO_2 concentration was between 16 and 28 percent for the first 300 hours of operation if the second analysis is ignored. The general trend of the SiO_2 concentration from hour 300 to 900 was a gradual rise in SiO_2 concentration from 15 to 27 percent. The increase in coal rate for the last 100 hours of TC06 then decreased the SiO_2 concentration to 17 percent. The source of SiO_2 in the PCD fines could be from start-up sand, coal ash, or limestone.

The trends in the TC06 fine ash CaO concentrations were similar to the SiO_2 concentrations. The CaO concentration was between 10 and 25 percent for the first 300 hours of operation. The general trend of the CaO concentration from hour 300 to 900 was a gradual rise from 18 to 30 percent. The increase in coal rate for the last 100 hours of TC06 then decreased the CaO concentration to 20 percent. The source of CaO in the PCD fines could be from the coal ash or limestone.

Figure 4.4-9 and Table 4.4-4 show the amounts of $CaCO_3$ and CaS in the PCD solids as sampled from FD0520. Also, shown in Figure 4.4-9, are the in situ solids concentrations for $CaCO_3$ and CaS. The in situ samples $CaCO_3$ concentration was consistently about 0.5 to 2.0 percent higher than the $CaCO_3$ concentration from the samples collected at FD0520. The lower $CaCO_3$ concentration is a result of a lower measured CO_2 in the FD0520 solids. This may be due to the FD0520 samples being slightly degassed in the PCD or FD0520 by aeration or backpulse nitrogen. The in situ CaS and FD0520 CaS sample analyses agreed with each other during TC06.

For the first 220 hours, the $CaCO_3$ concentration was constant at between 6 and 9 percent if one sample is ignored. The $CaCO_3$ concentration then slowly decreased between 280 hours and 800 hours from 10 to 5 percent. The PCD fines calcination is defined as:

$$\%\ \text{Calcination} = \frac{\text{M\% CaO}}{\text{M\% CaO} + \text{M\% CaCO}_3} \qquad (1)$$

The PCD fines calcination is shown in the plot in Figure 4.4-10. The PCD fines calcination increased between hours 240 and 800 from about 80 to 90 percent. From hours 860 to 977, the PCD fines calcination decreased down to 82 percent. The data does not indicate 80-percent limestone calcination since the calcium in the PCD fines comes from both the PRB ash and the limestone fed as sorbent. The percent limestone calcination is compared with the CO_2 partial pressure in Section 4.5.

The PCD fines CaS concentrations shown in Figure 4.4-9 varied from 3.5 percent to nearly 0.0 percent with no real pattern. This indicates a large variation of sulfur removal during TC06. The calcium sulfation is defined as:

$$\%\text{Sulfation} = \frac{\text{M\%CaS}}{\text{M\%CaO} + \text{M\%CaCO}_3 + \text{M\%CaS}} \qquad (2)$$

The PCD fines sulfation was below 15 percent for all of TC06 and usually below 10 percent indicating poor calcium utilization. Again, the calcium in the PCD fines came from both the sorbent and the PRB ash.

Table 4.4-4 provides the PCD fines compositions for the samples collected in FD0520. The consistency is excellent in that the totals add up to between 96.0 and 104.3 percent. Additional components in Table 4.4-4, other than those shown in the plot in Figures 4.4-7, -8, and -9, are

MgO, Fe_2O_3, and Al_2O_3. The MgO concentration was between 5 and 8 percent during TC06. The Fe_2O_3 concentration was between 2.6 and 4.4 percent. The Al_2O_3 concentration was between 6 and 11 percent. Also given on Table 4.4-4 are the HHV, LHV, and volatiles for the PCD gasification ash (fines). As expected, the trend of heating values follows the carbon content of the PCD fines.

Nine FD0510 solid samples were taken during TC06, but they were not analyzed because the standpipe samples should give a more accurate view of the circulating solids composition.

FD0510 samples were taken while the reactor was being drained of solids on September 24 and 25, 2001, after TC06 testing was complete. Table 4.4-5 provides analyses of six samples collected from FD0510 while the reactor was being drained of solids. The main component was SiO_2 at 32 to 47 percent. The solids sampled first, shown in Table 4.4-5, are solids from the bottom of the reactor. The six samples do not indicate that any of the components were being segregated at the top or bottom of the reactor.

The Sauter mean diameter (SMD) and mass mean diameter (D_{50}) particle size of the coal feed to the Transport Reactor in TC06 are shown in the plot on Figure 4.4-11. The coal SMD particle size varied a lot during the first 100 hours of operation between 160 and 350 µm. After hour 110, the coal became finer and was between 125 and 175 µm SMD. The period from hour 150 to hour 300 was a period of numerous coal trips which coincided with the coal SMD diameter being less than 175 µm. At hour 260, the SMD increased to about 200 µm and was steady at 200 µm, until hour 401, when it decreased to about 175 µm. The particle size was then constant between 150 and 210 µm until hour 580. At hour 600, the SMD decreased to 100 microns, with one sample as low as 90 µm. The period from hour 600 to hour 750 was a period of numerous coal trips which also coincided with fine coal fed to the reactor. The particle size then increased to 225 µm at hour 800. The SMD particle size was then steady between 175 and 250 µm from hour 800 until the end of TC06. This was a period of only one coal trip.

The D_{50} was 50 to 100 µm larger than the SMD during TC06.

A measure of the amount of fines in the coal would be the percent of the smallest size fraction present. High fines content could result in increased number of coal feeder outages due to coal feeder plugging caused by the packing of coal fines. To show the level of fines in the coal feed, the percent of ground coal less than 45 µm is plotted in Figure 4.4-12. The fines percent was 3 to 14 percent during the first 100 hours of testing. The coal fines then increased to between 20 and 30 percent from hours 150 to 200. This was a period of numerous coal trips. After the 4-week break, the coal fines decreased down to between 5 and 10 percent from hours 278 to 361. The fines were at 20 to 25 percent around hour 440. From hours 500 to 650, the fines were at 5 to 15 percent. The coal fines spiked up again at hour 645 and increased up to 44 percent at hour 750. During this period of high coal fines, there were numerous coal trips. The fines percent then decreased down to below 15 percent at hour 790. The coal fines remained below 15 percent for the remainder of TC06. This final period of low coal fines was during a period of only one coal feeder trip.

The SMD and D_{50} of the solids sampled from the sorbent feeder FD0220 are shown in the plot in Figure 4.4-13. The SMD was usually between 10 to 20 µm for the first 260 hours of TC06. Between hours 361 and 500, the sorbent particle size averaged about 10 µm. From hours 500 to 750, the particle size was between 7 and 15 µm SMD with one sample above 20 µm. Around hour 800, the SMD increased to 20 µm for three samples. After hour 810, the particle size was between 4 and 12 µm. The D_{50} was consistently higher than the SMD. The high spikes of SMD result in high spikes of 50 and 60 µm D_{50}.

The TC06 standpipe solids particulate sizes are shown in Figure 4.4-14. The particle size of the solids increased as the start-up sand was replaced by CaO and Al_2O_3. The SMD of the reactor solids increased from 150 to 175 µm during the first 220 hours of operation. After the reactor solids were replaced by fresh sand during the 4-week break, the reactor solids SMD fell to 140 µm. From hours 200 to 700 the reactor solid SMD increased from 140 to 180 µm. After the reactor solids concentration stopped changing at hour 700, the SMD was between 160 and 180 µm. The D_{50} was consistently about 20 µm less than the SMD.

Figure 4.4-15 shows the plot of the SMD and D_{50} for the PCD solids sampled from FD0520. The PCD fines SMD was fairly constant for the first 500 hours of TC06 at about 10 µm. From hours 500 to 800, the SMD slowly increased from 10 to 13 microns. When the coal rate was increased, the SMD then slowly decreased back down to about 11 µm. The D_{50} showed the same trend as the SMD, starting the run at 15 µm, then increasing to 20 µm, and then falling back down to 15 µm.

Figure 4.4-16 shows a plot of all the solids SMD particle size. The Transport Reactor is fed 300 µm coal and 10 µm limestone and produces 150 µm reactor solids and 10 µm PCD fines. The coal, reactor solids, and PCD fines particle sizes were essentially constant during TC06, while the limestone particle size was slowly decreasing.

The TC06 standpipe bulk densities are shown in Figure 4.4-17. The bulk density of the solids decrease slightly as the start-up sand is replaced by CaO and Al_2O_3. The standpipe solids bulk density decreased from 90 to 85 lb/ft^3 during the first 220 hours of operation. After the reactor solids were replaced by fresh sand during the 4-week break, the reactor solids bulk density returned to about 90 lb/ft^3. From hours 220 to 700, the bulk density decreased from 90 lb/ft^3 per cubic foot to between 80 and 85 lb/ft^3. The bulk density then remained at between 80 and 85 lb/ft^3 until the end of TC06 and after the reactor solids had reached the steady-state composition at hour 700.

Figure 4.4-17 is a plot of the bulk density for the PCD solids sampled from FD0520. For the first 200 hours, the bulk density of the PCD fines was about 20 lb/ft^3. After the 4-week break the PCD fines bulk solids were constant at between 20 and 30 lb/ft^3 from hours 220 to 724. During the period of low coal-feed rate, the bulk density increased to nearly 30 lb/ft^3. When the coal-feed rate was increased, the bulk density decreased to 25 lb/ft^3.

Table 4.4-1 Coal Analyses

	Value	Standard Deviation
Moisture, Wt%	20.93	1.08
Carbon, Wt%	57.02	1.04
Hydrogen[1], Wt%	3.74	0.12
Nitrogen, Wt%	0.66	0.05
Sulfur, Wt%	0.26	0.02
Ash, Wt%	5.23	0.45
Volatiles, Wt%	37.39	8.83
Fixed Carbon, Wt%	36.46	9.44
Higher Heating Value, Btu/lb	9,391	129
Lower Heating Value, Btu/lb	8,828	133
CaO, Wt %	1.27	0.13
SiO_2, Wt %	1.66	0.24
Al_2O_3, Wt %	0.88	0.10
MgO, Wt %	0.28	0.02
Fe_2O_3, Wt %	0.33	0.06
Ca/S, mole/mole	2.83	0.29
Fe/S, mole/mole	0.51	0.07

1. All analyses are as sampled at FD0210.
2. Hydrogen in coal is reported separately from hydrogen in moisture.
3. Samples AB08556 and AB08558 excluded.

Table 4.4-2 Limestone Analysis

Compound	Weight %	Standard Deviation
$CaCO_3$	75.95	1.29
$MgCO_3$	17.66	0.76
$CaSO_4$	0.42	0.33
SiO_2	2.58	0.32
Al_2O_3	0.93	0.27
Other Inerts[2]	0.65	0.39
H_2O	0.15	0.04
Total	98.34	

1. All analyses are as sampled at FD0220.
2. Other inerts consist of Fe_2O_3, P_2O_5, Na_2O, K_2O, and TiO_2.

Table 4.4-3 Standpipe Analysis

Sample Number	Sample Date & Time	Sample Run Time Hours	SiO_2 Wt. %	Al_2O_3 Wt. %	Fe_2O_3 Wt. %	Other Inerts[1] Wt. %	$CaCO_3$ Wt. %	CaS Wt. %	CaO Wt. %	MgO Wt. %	Organic Carbon Wt. %	Total Wt. %
AB08565	7/15/01 8:00	7	80.4	3.2	1.0	1.3	0.0	0.2	3.1	0.6	2.9	92.7
AB08566	7/15/01 12:00	11	86.9	4.2	1.4	1.1	0.1	0.2	3.9	0.7	1.6	100.2
AB08567	7/15/01 20:30	20	85.5	4.4	1.5	1.2	0.2	0.3	4.7	0.8	2.0	100.6
AB08568	7/16/01 4:00	27	84.9	6.0	1.5	1.3	0.2	0.2	4.5	0.8	0.5	100.0
AB08577	7/16/01 12:00	35	81.6	5.4	1.7	1.6	0.3	0.1	7.3	1.2	0.6	99.8
AB08578	7/16/01 20:00	43	82.8	5.1	2.0	1.4	0.2	0.0	7.3	1.2	0.4	100.3
AB08613	7/17/01 12:00	59	76.5	7.4	1.6	1.8	0.1	0.0	10.2	1.6	0.2	99.3
AB08615	7/18/01 4:00	75	66.7	7.5	2.1	2.1	0.2	0.0	17.6	2.6	0.1	99.0
AB08639a	7/18/01 12:00	83	67.2	7.2	2.7	2.1	0.1	0.2	17.2	2.6	0.4	99.6
AB08639	7/18/01 12:00	83	67.7	7.3	2.7	2.3	0.0	0.0	17.0	2.6	0.2	99.7
AB08640	7/18/01 20:00	91	70.0	6.8	2.8	2.0	0.2	0.3	15.7	2.4	0.2	100.4
AB08641	7/19/01 4:00	99	74.3	7.8	2.5	2.2	0.0	0.0	11.6	1.7	0.3	100.2
AB08667	7/19/01 20:00	115	70.1	8.1	2.3	2.3	0.0	0.0	14.4	2.1	0.1	99.5
AB08683	7/20/01 12:00	131	68.0	8.2	2.7	2.4	0.0	0.0	16.4	2.2	0.4	100.2
AB08684	7/21/01 12:45	156	65.8	9.2	2.8	2.4	0.0	0.0	16.7	2.2	0.1	99.2
AB08685	7/22/01 12:00	179	59.8	9.4	3.3	2.5	0.1	0.0	21.3	2.8	0.4	99.6
AB08686	7/22/01 20:00	187	62.8	8.8	3.9	1.9	0.0	0.0	20.1	2.5	0.2	100.2
AB08687	7/23/01 4:00	195	60.5	9.0	4.1	2.0	0.0	0.0	21.8	2.7	0.2	100.3
AB08725	7/23/01 12:01	203	64.0	10.1	4.2	2.5	0.0	0.0	17.7	2.3	0.3	101.2
AB08827	8/21/01 8:00	243	81.7	4.7	3.9	1.7	0.2	0.1	8.5	1.3	1.0	103.0
AB08834	8/21/01 20:00	255	81.2	4.2	1.4	1.6	0.3	0.0	9.6	1.4	0.2	99.8
AB08847	8/23/01 0:00	266	79.6	5.2	1.4	1.5	0.2	0.0	9.2	1.3	1.3	99.7
AB08859	8/23/01 12:00	278	73.7	6.5	1.7	1.8	0.3	0.1	12.6	1.9	8.9	107.4
AB08861	8/23/01 20:00	286	76.6	6.1	2.0	1.9	0.3	0.1	9.5	1.4	1.5	99.4
AB08874	8/25/01 20:00	321	73.1	7.4	1.5	2.3	0.3	0.1	9.9	1.5	0.5	96.5
AB08878	8/26/01 20:00	345	72.6	6.9	1.8	2.1	0.3	0.0	13.7	2.0	0.3	99.7
AB08944	8/27/01 8:00	357	70.0	8.6	2.1	2.5	0.3	0.4	13.1	1.9	0.4	99.3
AB08958	8/28/01 16:00	385	68.8	9.5	2.1	2.6	0.3	0.1	14.3	2.0	0.6	100.3
AB08979	8/29/01 20:00	413	64.1	9.0	2.3	2.5	0.3	0.3	18.7	2.4	0.1	99.8
AB09006	8/30/01 20:00	437	60.4	9.9	2.5	2.8	0.2	0.2	20.7	2.6	0.8	100.1
AB09108	9/5/01 20:00	581	48.9	11.3	2.9	3.1	0.3	0.0	29.1	3.5	0.4	99.5
AB09191	9/11/01 4:00	709	42.1	14.6	3.8	3.0	0.2	0.3	31.3	4.5	0.0	99.8
AB09206	9/11/01 16:00	721	39.2	13.3	4.6	2.6	0.3	0.1	34.1	5.0	1.2	100.5
AB09242	9/13/01 4:00	757	39.0	13.3	4.6	2.7	0.3	0.5	33.9	4.9	0.9	100.1
AB09247	9/13/01 20:00	773	33.4	12.0	4.4	2.9	0.5	0.3	41.5	5.3	0.5	100.7
AB09274	9/14/01 8:00	785	36.2	16.0	4.1	3.1	0.3	0.2	36.0	4.7	0.1	100.7
AB09277	9/15/01 8:00	809	36.2	12.1	3.8	3.1	0.4	0.3	39.8	4.7	0.1	100.5
AB09283	9/16/01 8:00	833	33.3	12.4	3.6	3.1	0.4	0.2	41.6	5.3	0.1	100.0
AB09321	9/17/01 12:00	861	30.5	13.5	3.6	3.2	0.4	0.4	42.5	5.7	0.0	99.7
AB09345	9/18/01 16:00	889	32.4	13.3	3.8	3.3	0.3	0.2	41.6	5.1	0.3	100.4
AB09353	9/19/01 16:00	913	33.4	14.2	3.7	3.6	0.3	0.2	39.5	5.3	0.1	100.3
AB09376	9/20/01 20:00	941	32.4	14.4	3.8	3.4	0.3	0.2	39.9	5.5	0.1	100.1
AB09425	9/21/01 20:00	965	34.4	14.7	3.9	3.7	0.2	0.3	37.1	5.2	0.2	99.7
AB09427	9/22/01 20:00	989	38.2	15.5	4.0	4.0	0.3	0.2	32.8	4.8	1.3	101.1
AB09433	9/23/01 20:00	1013	36.5	15.4	3.8	3.7	0.3	0.1	34.4	4.8	0.3	99.3
AB09453	9/24/01 12:00	1029	36.3	15.2	3.9	3.7	0.3	0.1	35.7	4.9	0.4	100.3

1. Other inserts consist of P_2O_5, Na_2O, K_2O, and TiO_2.

Table 4.4-4 PCD Fines From FD0520

Sample Number	Sample Date & Time	Sample Run Time Hours	SiO_2 Wt. %	Al_2O_3 Wt. %	Fe_2O_3 Wt. %	Other Inerts[1] Wt. %	$CaCO_3$ Wt. %	CaS Wt. %	CaO Wt. %	MgO Wt. %	Organic C ($C-CO_2$) Wt. %	Total Wt. %	HHV Btu/lb.	LHV Btu/lb.
AB08559	7/15/01 8:00	7	19.1	6.5	3.3	1.7	7.8	3.4	10.5	3.6	46.3	102.2	6,888	6,815
AB08560	7/16/01 0:01	23	35.9	6.8	2.6	1.8	4.4	2.2	7.9	2.5	40.1	104.3	5,490	5,433
AB08561	7/16/01 8:00	31	28.0	8.0	2.9	2.2	7.2	2.8	13.9	4.3	30.7	100.0	4,797	4,749
AB08580	7/16/01 16:00	39	22.9	9.5	3.7	2.6	7.3	1.9	23.1	5.6	25.4	101.8	3,855	3,806
AB08582	7/17/01 8:00	55	21.3	9.7	3.6	2.5	7.7	0.6	24.5	5.6	26.4	101.8	3,605	3,554
AB08618	7/18/01 8:00	79	19.1	8.5	3.0	2.0	8.0	1.0	22.6	5.5	30.1	99.9	4,425	4,369
AB08669	7/19/01 8:00	103	16.5	8.4	3.4	2.1	8.9	1.0	25.1	6.0	28.5	100.0	4,313	4,261
AB08671	7/20/01 8:00	127	17.3	8.3	3.5	2.1	8.6	1.1	23.6	5.7	32.0	102.3	4,442	4,384
AB08706	7/21/01 10:00	153	23.1	8.8	3.4	2.1	7.6	1.1	23.8	5.6	25.0	100.4	3,782	3,735
AB08708	7/22/01 8:00	175	16.6	7.4	3.1	1.9	6.6	2.8	10.0	3.2	49.9	101.3	7,408	7,341
AB08709	7/22/01 16:00	183	19.1	9.8	4.0	2.1	5.8	2.7	11.9	3.3	43.4	102.1	6,359	6,290
AB08710	7/23/01 8:00	199	19.7	9.3	4.0	2.4	8.1	1.5	23.4	5.6	26.6	100.5	4,041	3,996
AB08729	7/24/01 8:00	223	21.3	9.4	4.4	2.3	6.8	1.3	20.4	5.1	30.1	101.0	4,353	4,296
AB08816	8/21/01 8:00	243	23.7	8.9	3.2	2.3	7.2	0.7	20.0	5.3	27.9	99.3	4,164	4,105
AB08835	8/21/01 19:00	254	23.8	7.5	2.8	2.4	6.5	0.5	21.1	4.9	32.8	102.4	4,437	4,387
AB08862	8/23/01 16:00	282	14.4	6.2	2.5	2.0	10.0	1.1	20.0	5.1	39.1	100.3	5,899	5,837
AB08886	8/25/01 16:00	317	13.6	6.2	2.2	1.7	9.4	1.8	18.7	5.3	40.2	99.0	6,109	6,049
AB08889	8/26/01 16:00	341	14.6	5.8	2.0	1.7	8.4	1.7	19.7	5.0	40.1	99.0	5,856	5,798
AB08890	8/27/01 0:00	349	16.5	6.8	2.2	1.6	8.3	1.7	18.1	5.1	40.6	101.0	6,032	5,965
AB08891	8/27/01 8:00	357	17.3	6.3	2.2	1.8	8.4	1.5	21.3	5.2	32.0	96.0	4,855	4,805
AB08959	8/28/01 16:00	385	16.2	6.7	2.7	2.1	8.8	2.1	19.2	5.1	38.2	101.1	5,201	5,145
AB08961	8/29/01 8:00	401	20.8	8.5	2.9	2.1	7.8	2.2	18.1	5.2	34.1	101.8	5,128	5,072
AB08977	8/30/01 0:00	417	19.5	7.8	3.1	2.4	8.4	1.0	23.8	5.8	26.9	98.7	4,159	4,118
AB08999	8/30/01 8:00	425	23.0	8.5	3.1	2.3	7.8	0.7	21.8	5.3	26.3	98.7	4,029	3,983
AB09000	8/31/01 0:00	441	17.2	7.5	2.9	2.4	7.7	1.8	20.2	5.4	34.1	99.1	5,212	5,161
AB09038	9/1/01 0:01	465	20.9	8.1	3.1	2.6	6.8	0.7	23.5	5.5	28.8	99.9	4,086	4,038
AB09040	9/1/01 16:00	481	18.0	7.6	3.2	2.4	8.1	1.1	22.1	5.6	32.6	100.7	4,983	4,933
AB09042	9/2/01 16:00	505	20.3	8.1	3.2	2.5	7.4	0.9	24.1	5.6	26.6	98.8	4,077	4,032
AB09051	9/3/01 12:00	525	24.1	9.0	3.1	2.3	7.3	0.8	21.6	5.3	28.0	101.5	4,068	4,021
AB09045	9/4/01 0:00	537	22.0	8.6	3.0	2.3	7.4	1.6	19.1	5.0	28.8	97.9	4,602	4,554
AB09082	9/4/01 16:00	553	22.0	8.4	3.0	2.2	6.6	0.7	19.7	5.0	30.2	97.8	4,642	4,583
AB09084	9/5/01 8:00	569	17.7	8.0	3.1	2.5	7.2	0.9	19.8	5.1	34.7	99.0	5,099	5,049
AB09110	9/6/01 8:00	593	18.2	7.6	3.1	2.4	6.8	1.9	18.5	4.9	32.8	96.2	4,759	4,705
AB09130	9/7/01 0:00	609	22.9	9.3	3.4	2.4	6.5	1.7	19.8	5.3	26.9	98.3	4,163	4,119
AB09161	9/7/01 16:00	625	26.5	10.1	3.7	2.8	4.9	0.6	25.6	5.4	20.1	99.8	3,032	3,001
AB09164	9/9/01 8:00	665	21.5	8.8	3.5	2.6	6.2	1.4	21.9	5.2	27.4	98.6	4,053	4,011
AB09166	9/10/01 0:00	681	20.5	9.1	3.6	2.8	7.1	2.1	22.3	5.8	25.8	99.2	3,867	3,828
AB09194	9/10/01 16:00	697	25.7	10.0	3.4	2.4	6.3	0.6	21.9	5.0	24.2	99.4	3,672	3,620
AB09195	9/11/01 8:00	713	21.9	8.9	3.1	2.2	7.4	1.1	19.4	4.9	30.0	98.9	4,602	4,547
AB09248	9/14/01 0:00	777	21.7	9.7	3.7	2.8	6.4	0.8	28.8	7.0	19.2	100.2	2,996	2,966
AB09249	9/14/01 8:00	785	22.7	9.5	3.5	2.7	5.9	0.9	26.0	6.3	20.2	97.8	3,082	3,050
AB09266	9/15/01 8:00	809	21.6	8.9	3.4	2.7	6.2	1.1	27.6	6.4	20.3	98.1	3,009	2,976
AB09269	9/16/01 8:00	833	21.5	9.0	3.6	2.7	7.0	0.7	31.1	8.1	15.1	98.9	2,392	2,366
AB09270	9/16/01 16:00	841	24.9	10.3	4.0	3.1	5.4	0.9	26.5	6.5	19.7	101.2	2,815	2,785
AB09273a	9/17/01 10:30	860	27.0	11.4	4.1	2.8	5.3	0.5	30.3	6.8	10.6	98.6	1,628	1,606
AB09314	9/18/01 0:00	873	26.9	11.3	4.0	2.8	5.6	0.7	28.9	6.5	13.0	99.7	2,064	2,037
AB09341	9/18/01 16:00	889	24.6	10.5	3.7	2.9	6.3	0.3	27.5	6.4	16.9	99.1	2,651	2,619
AB09359	9/19/01 16:00	913	24.0	11.0	3.3	2.8	6.3	0.9	23.5	6.0	21.1	98.9	3,132	3,094
AB09372	9/20/01 8:00	929	24.3	10.5	2.8	2.5	6.7	2.0	18.1	5.0	26.9	98.9	4,232	4,189
AB09373	9/20/01 16:00	937	22.4	9.6	2.9	2.8	6.7	2.0	20.8	5.4	29.1	101.7	4,214	4,167
AB09415	9/21/01 16:30	962	16.4	7.9	2.8	2.4	7.6	1.2	19.8	5.1	37.2	100.3	5,260	5,202
AB09417	9/22/01 8:00	977	18.7	8.4	2.8	2.4	6.5	1.6	16.8	4.4	41.8	103.5	5,669	5,601
AB09421	9/23/01 16:00	1009	17.8	8.2	2.9	2.4	6.6	1.7	18.8	4.7	40.3	103.3	5,511	5,451
AB09451	9/24/01 12:00	1029	18.6	8.5	3.0	2.4	7.8	2.1	20.9	5.6	33.2	102.1	4,968	4,916

Note: Other inerts consist of P_2O_5, Na_2O, K_2O, & TiO_2

Table 4.4-5 Reactor Samples From FD0510

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Sample Number	Sample Date & Time	SIO_2 Wt. %	Al_2O_3 Wt. %	Other Inerts[1] Wt. %	$CaCO_3$ Wt. %	CaS Wt. %	CaO Wt. %	MgO Wt. %	Organic C Wt. %	Total Wt. %
AB09454	9/24/01 16:15	42.8	12.3	6.9	0.5	0.2	30.4	4.3	0.2	97.7
AB09456	9/24/01 18:00	32.6	14.7	7.8	0.2	0.3	37.0	5.5	0.3	98.4
AB09458	9/24/01 20:00	33.8	14.8	7.7	0.2	0.2	37.7	5.4	0.3	100.0
AB09461	9/24/01 23:00	33.4	14.5	7.7	0.2	0.1	38.7	5.5	0.2	100.2
AB09463	9/25/01 1:00	37.9	15.0	7.8	0.3	0.1	34.2	4.8	0.3	100.3
AB09465	9/25/01 3:00	47.0	16.0	7.8	0.3	0.1	25.1	3.5	0.3	100.1

Notes:

1. Other inerts consist of Fe_2O_3, P_2O_5, Na_2O, K_2O, & TiO_2
2. 9/24 & 9/25 samples were taken at the end of TC06 while the reactor was being drained.

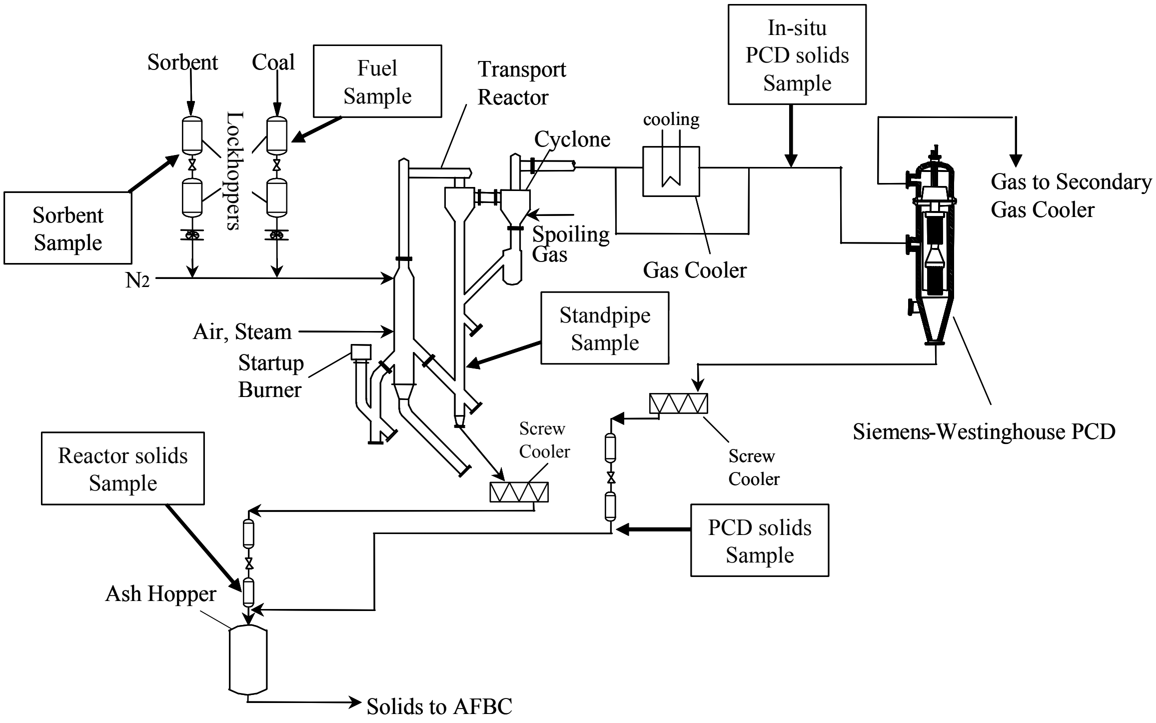

Figure 4.4-1 Solid Sample Locations

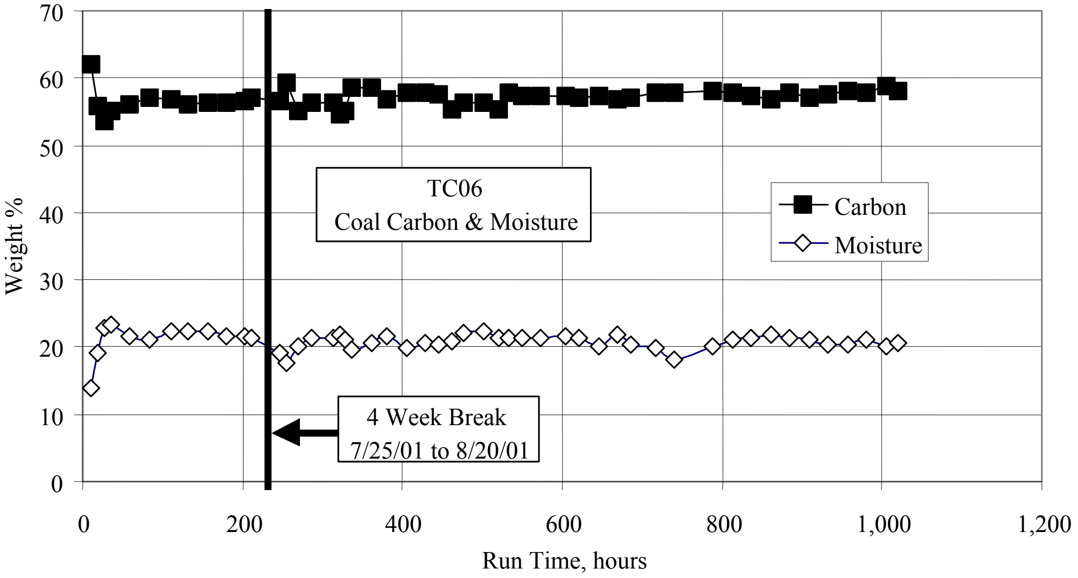

Figure 4.4-2 Coal Carbon and Moisture

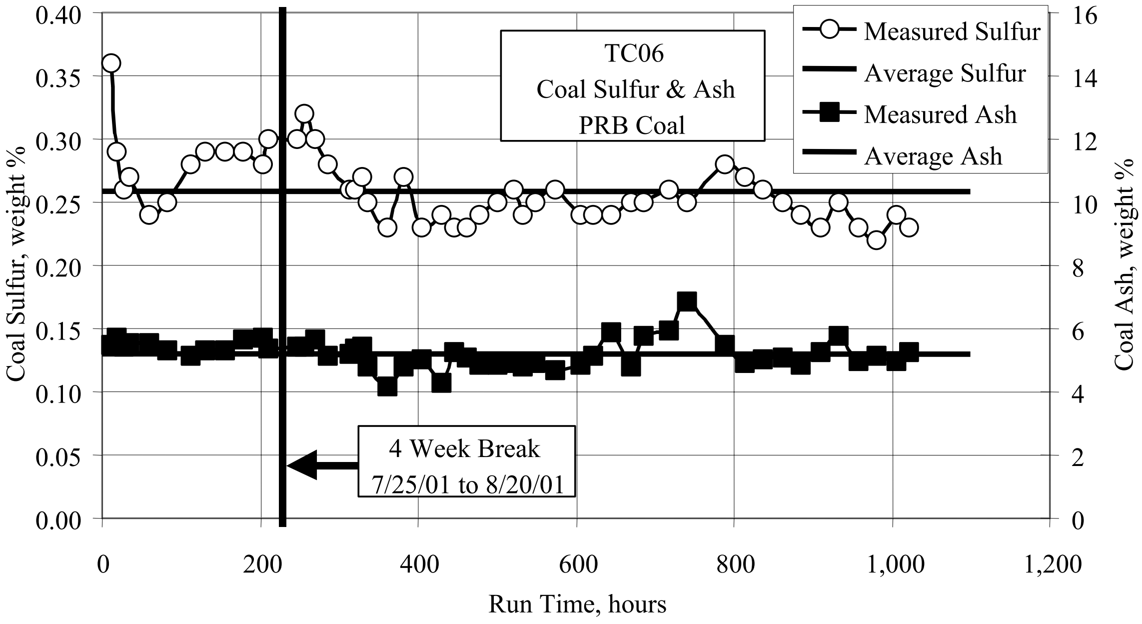

Figure 4.4-3 Coal Sulfur and Ash

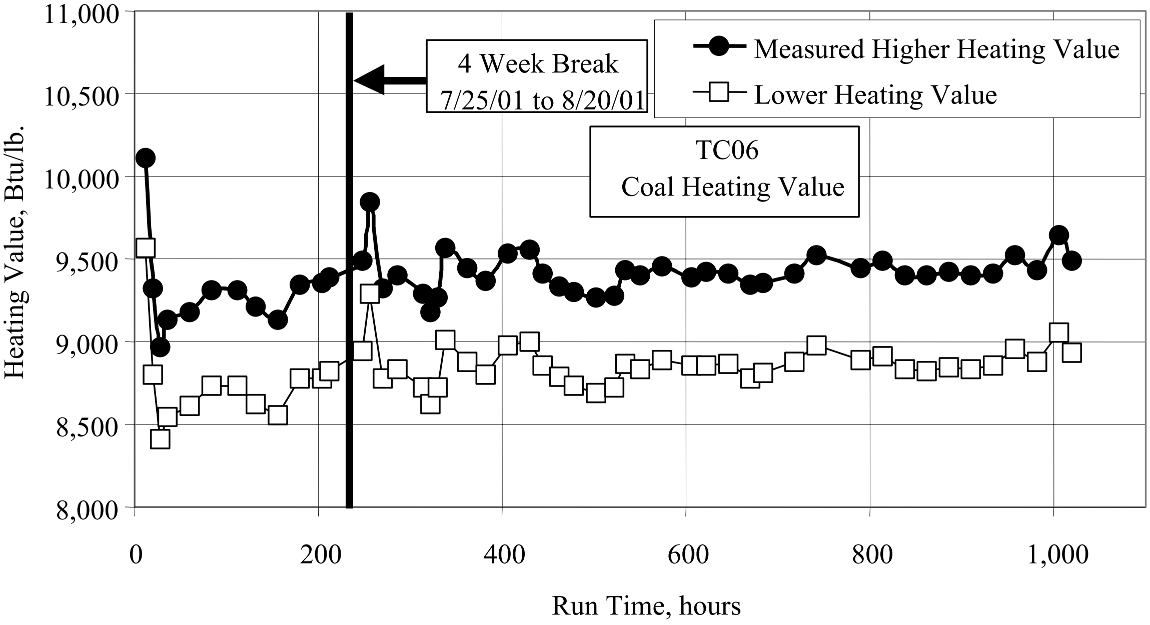

Figure 4.4-4 Coal Heating Value

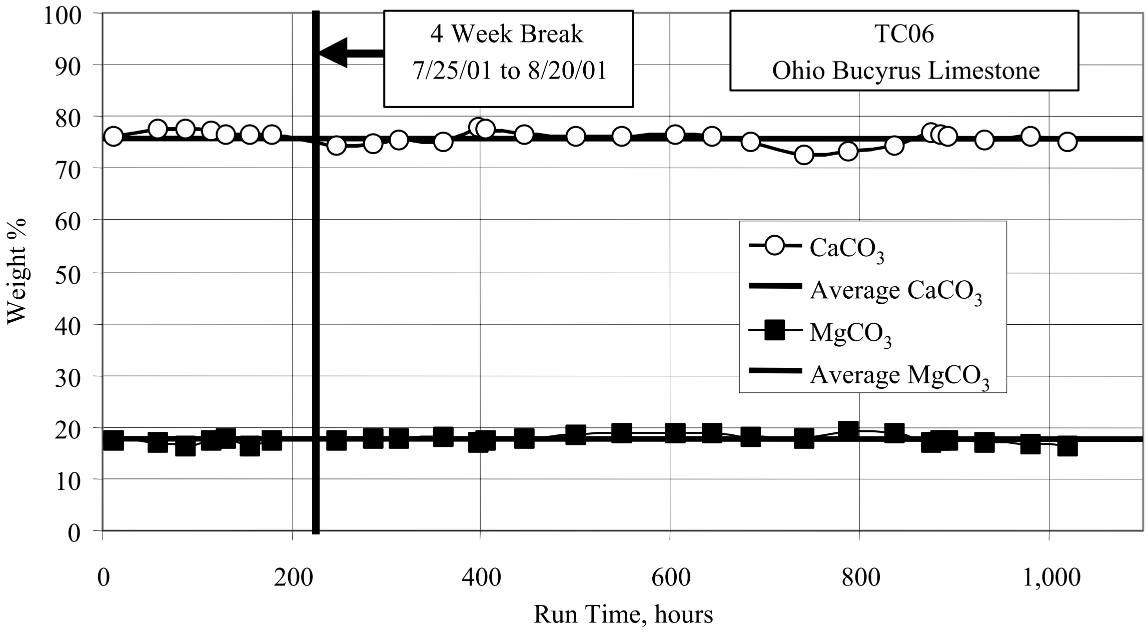

Figure 4.4-5 Limestone $CaCO_3$ and $MgCO_3$

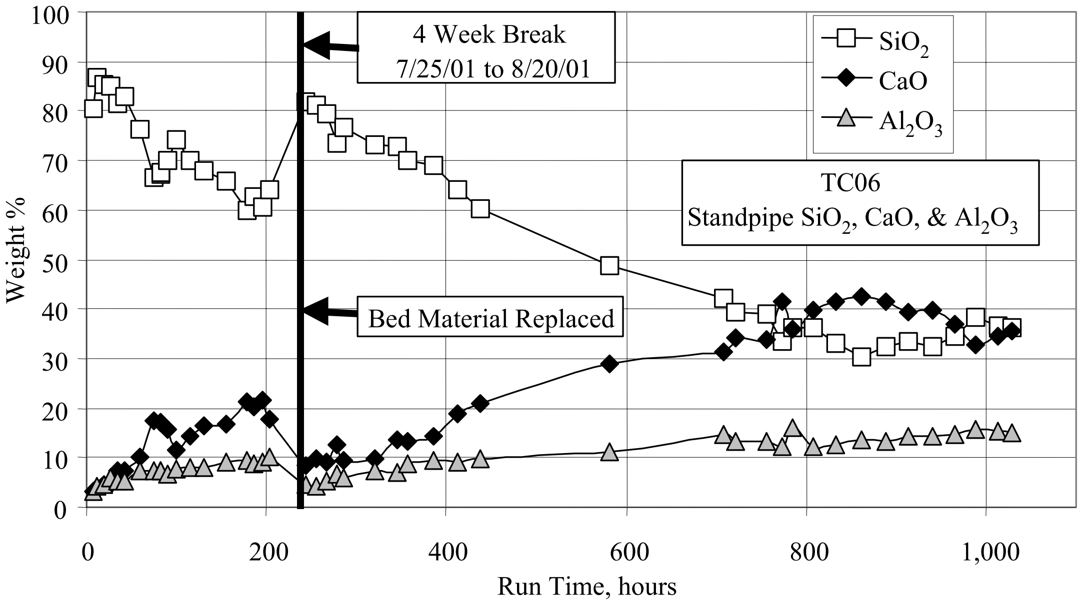

Figure 4.4-6 Standpipe SiO_2, CaO, and Al_2O_3

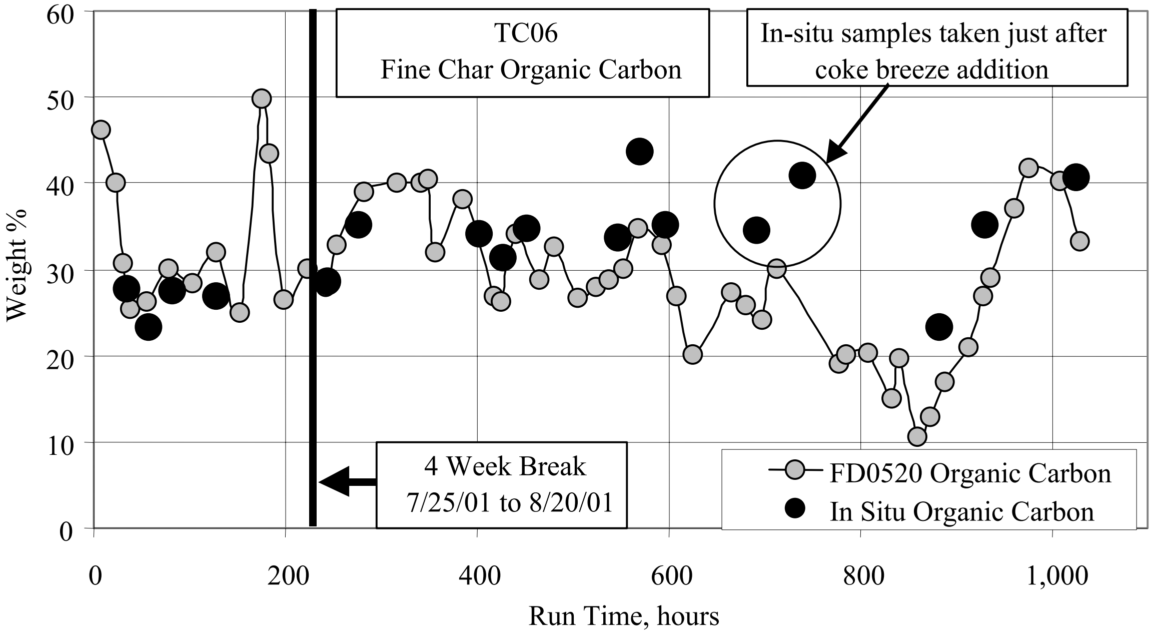

Figure 4.4-7 PCD Fines Organic Carbon

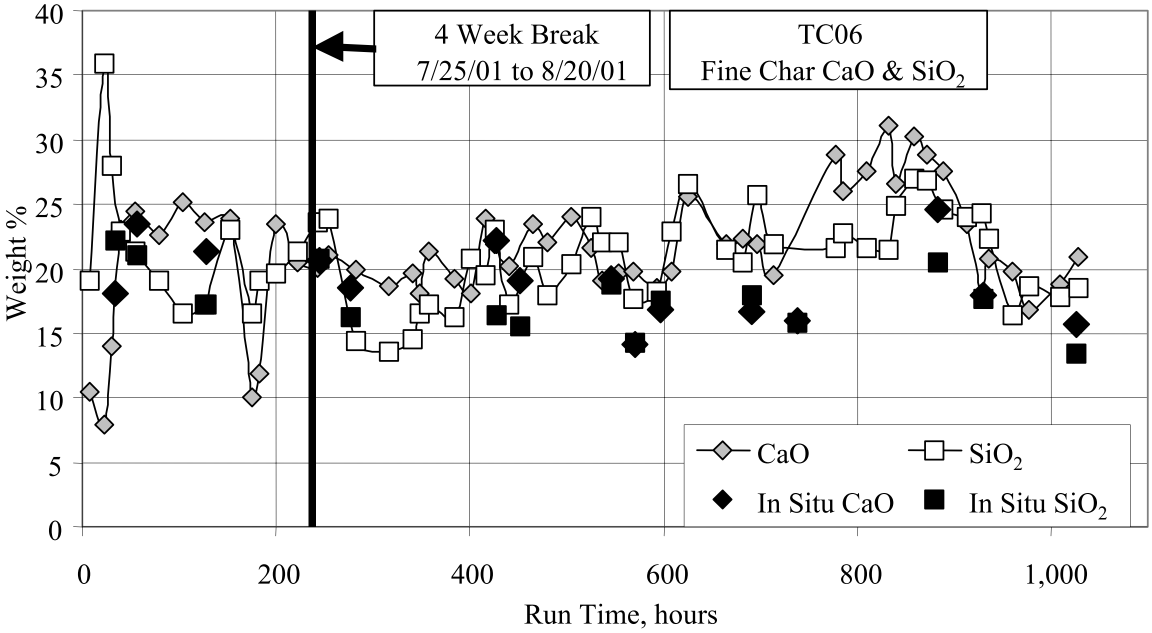

Figure 4.4-8 PCD Fines SiO_2, and CaO

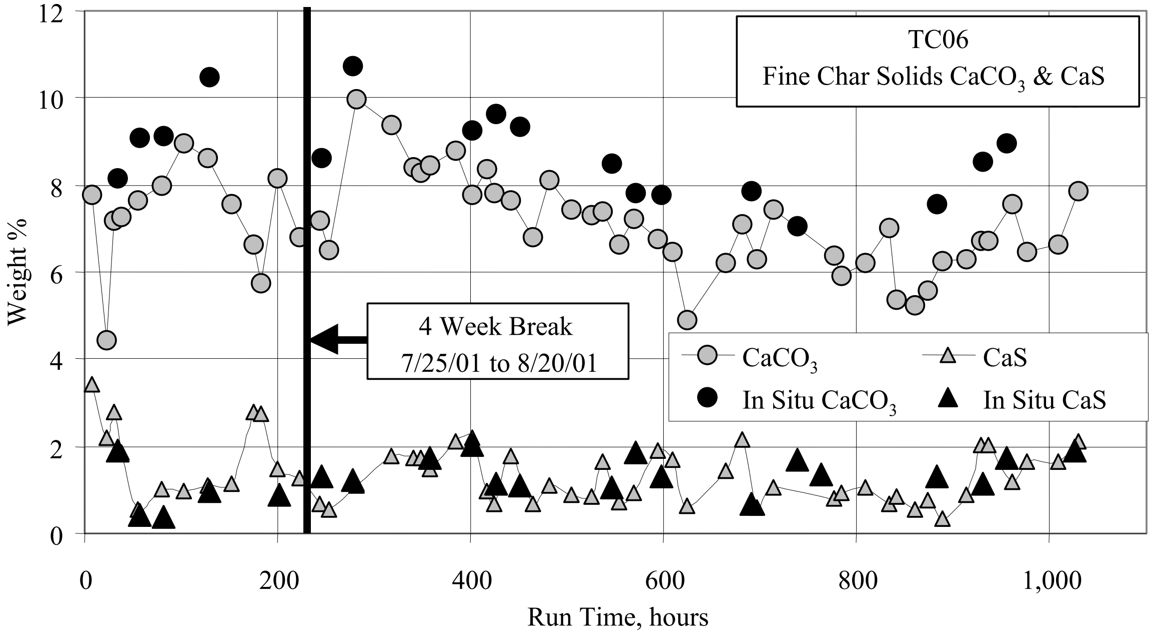

Figure 4.4-9 PCD Fines $CaCO_3$ and CaS

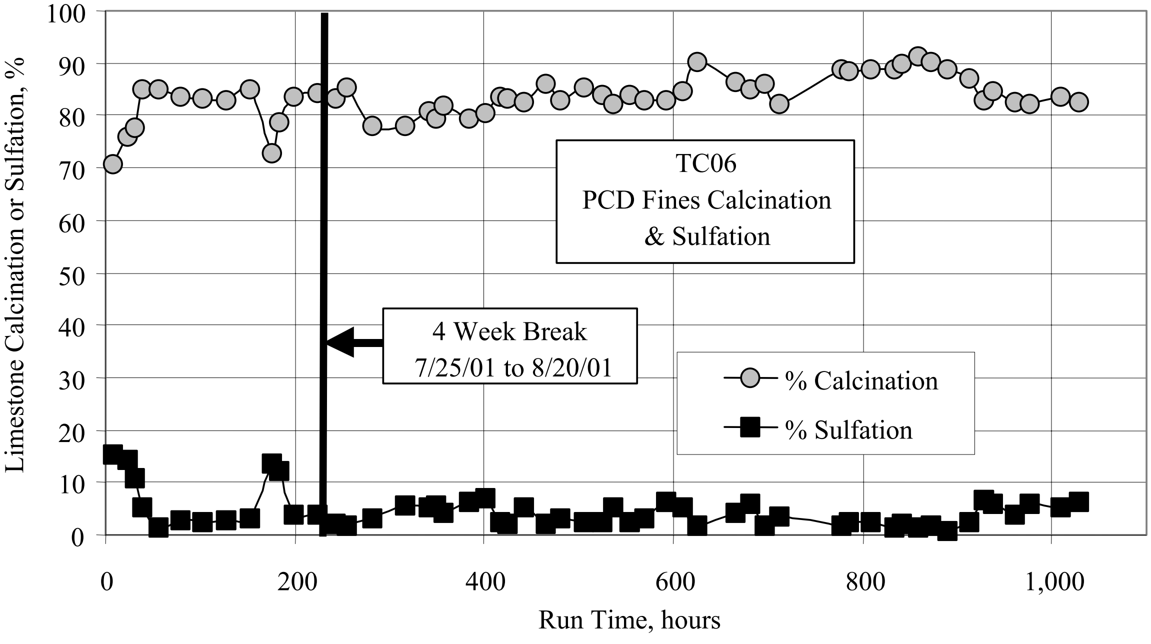

Figure 4.4-10 PCD Fines Calcination and Sulfation

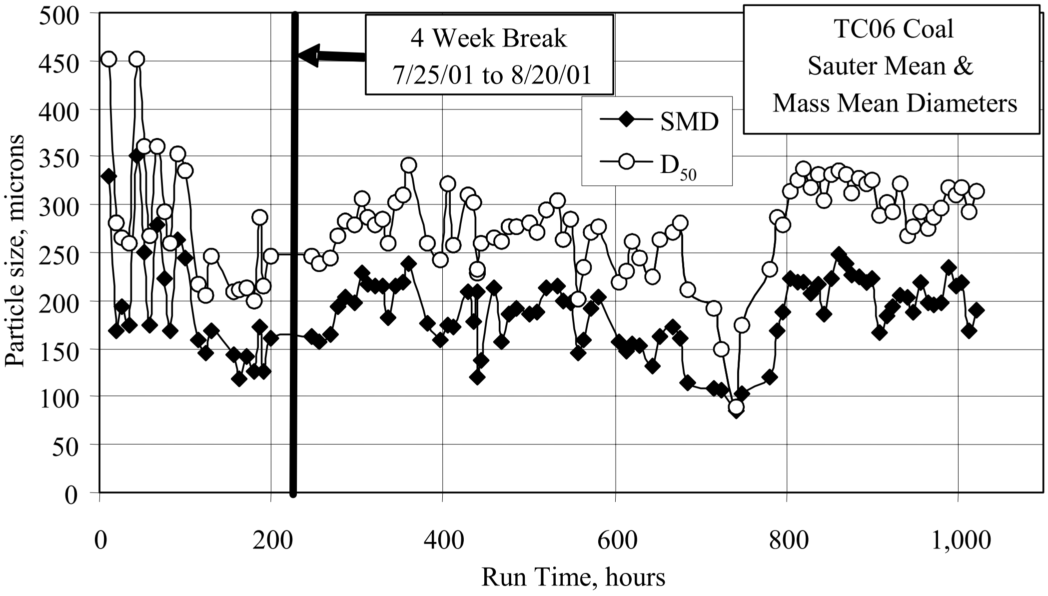

Figure 4.4-11 Coal Particle Size

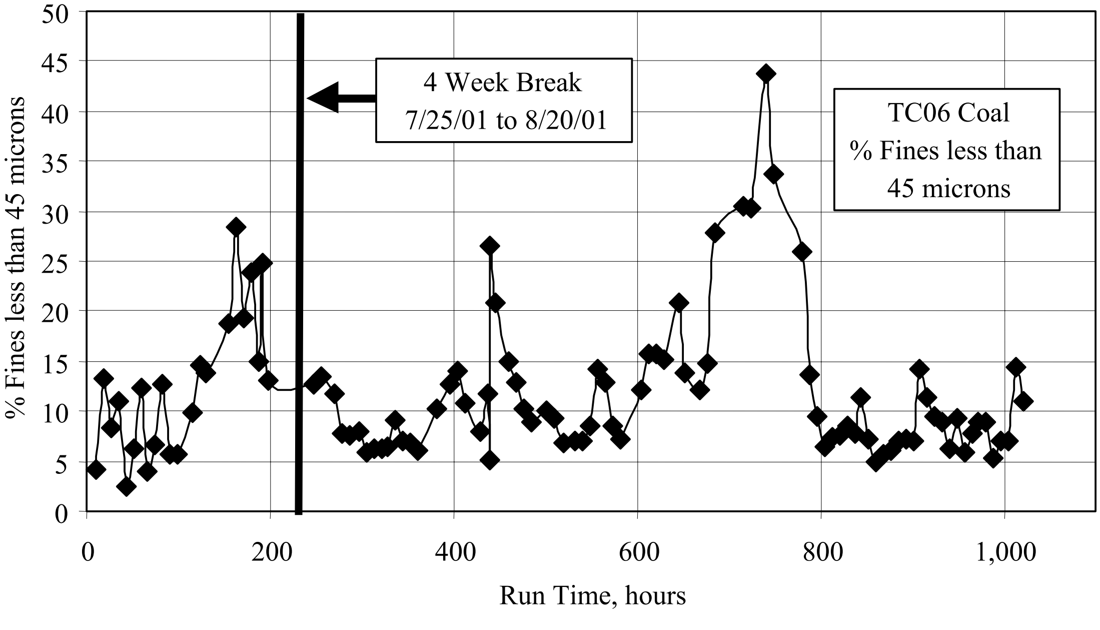

Figure 4.4-12 Percent Coal Fines

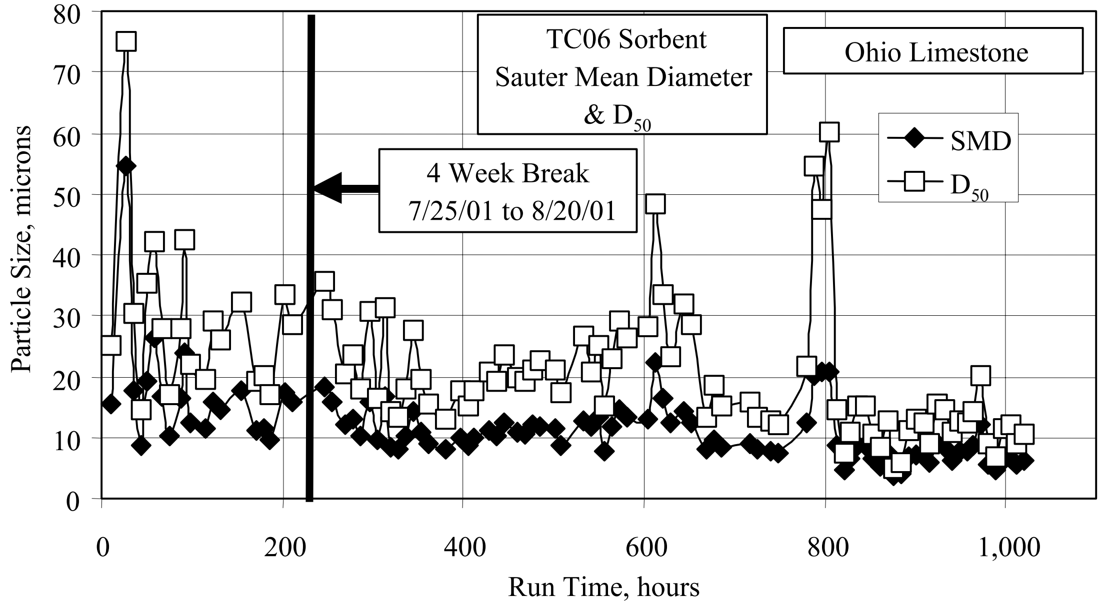

Figure 4.4-13 Sorbent Particle Size

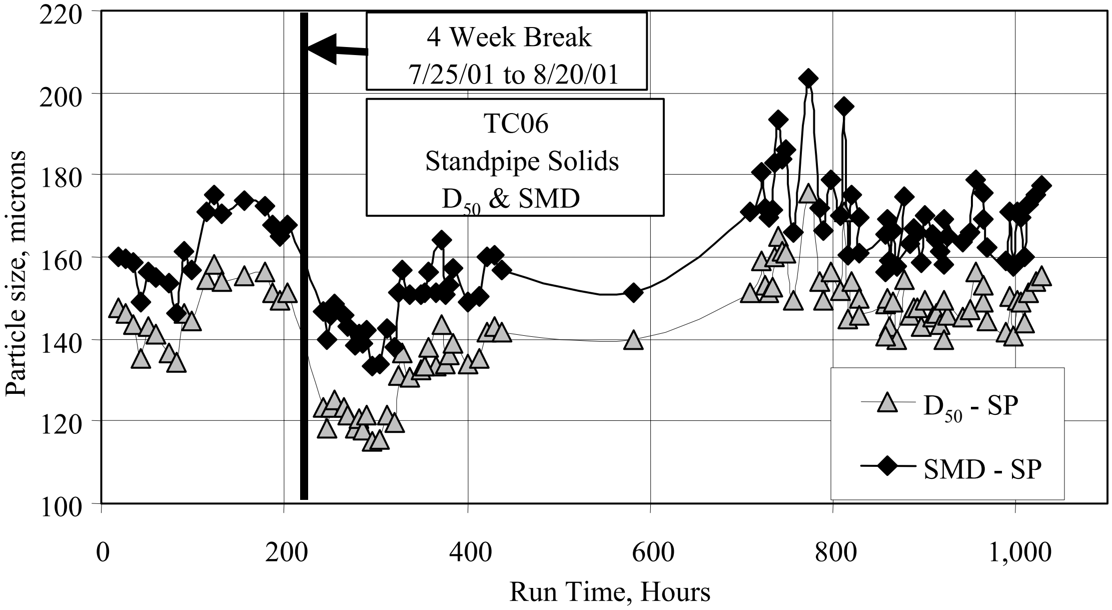

Figure 4.4-14 Standpipe Solids Particle Size

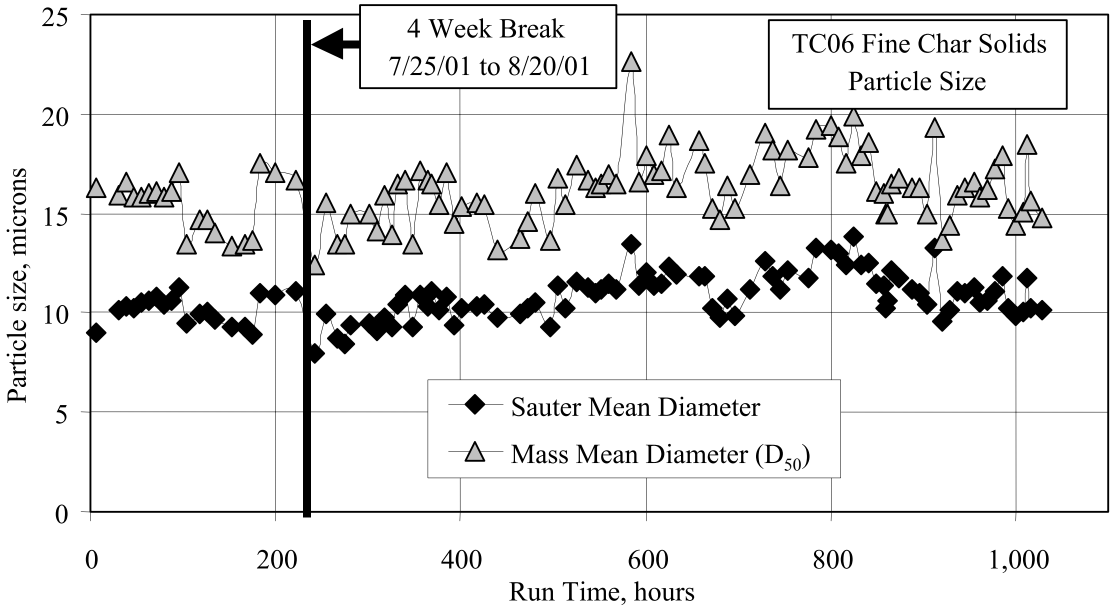

Figure 4.4-15 PCD Fines Particle Size

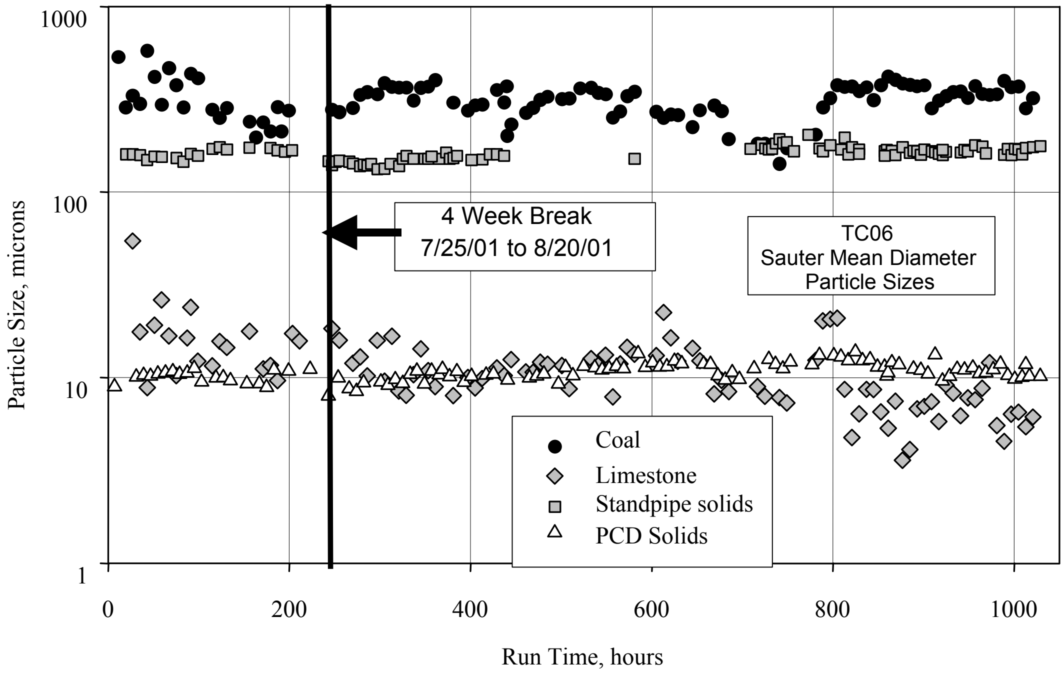

Figure 4.4-16 Particle-Size Distribution

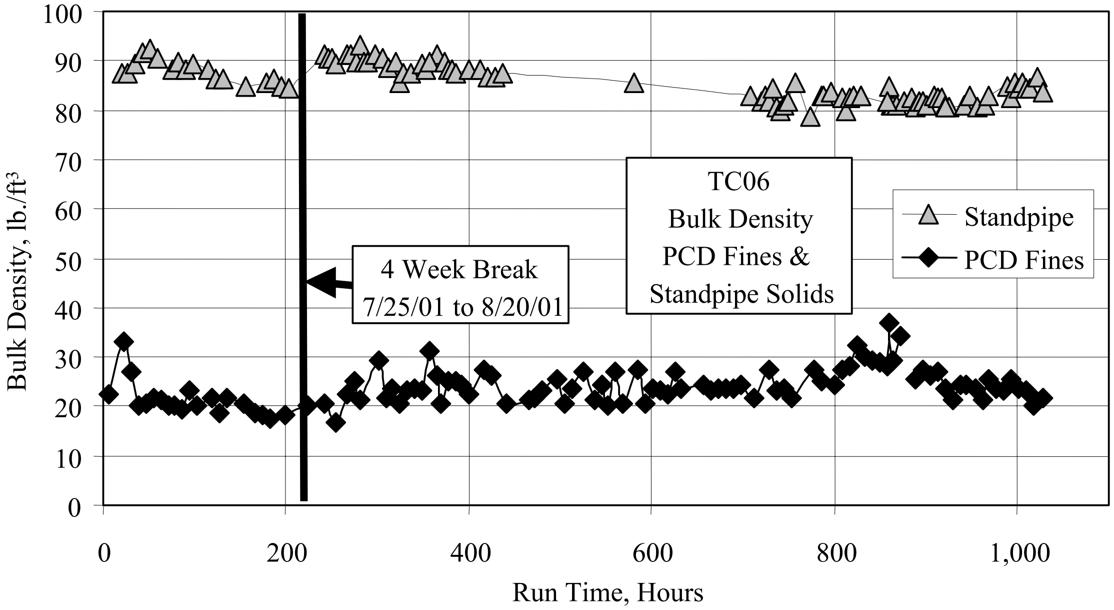

Figure 4.4-17 Standpipe and PCD Fines Solids Bulk Density

4.5 MASS AND ENERGY BALANCES

Using the gas analyses, solids analyses, and process flows entering and leaving the Transport Reactor, the following were determined:

- Coal rate.
- Overall mass balance.
- Nitrogen balance.
- Carbon conversion.
- Sulfur balance.
- Sulfur removal.
- Hydrogen balance.
- Oxygen balance.
- Calcium balance.
- Sulfur capture dependence on calcium-to-sulfur ratio.
- Silicon dioxide balance.
- Energy balance.
- Gasification efficiencies.

The process flows into the KBR Transport Reactor process are:

- Coal flow through FD0210.
- Sorbent flow through FD0220.
- Air flow measured by FI205.
- Nitrogen flow measured by FI609.
- Steam flow measured by FI204.

The process flows from the KBR Transport Reactor process are:

- Synthesis gas-flow rate from the PCD measured by FI465.
- PCD solids flow through FD0520.
- Reactor solids flow through FD0510.

The coal flow through FD0210 is usually determined by a correlation between feeder speed and coal dumps from the FD0210 surge bin between fills. In both GCT3 and GCT4 this method resulted in both carbon and energy balance being 10 to 20 percent high. It appeared that the coal rates determined from the FD0210 weigh cell data were consistently higher than actual. For TC06, the Transport Reactor carbon balance will be used to determine the coal rate. This is similar to the method used to determine the coal rate in combustion when the coal rate was determined by the flue gas rate, flue gas CO_2, and the fuel carbon.

The sorbent flow through FD0220 was determined from a correlation between feeder speed and sorbent dumps from the FD0220 storage bin between fills. This sorbent fill, feeder speed data, and correlation are shown in Figure 4.5-1. The correlation for the sorbent feeder is:

$$\text{Sorbent rate (lb/hr)} = 48.15(\text{rpm}) + 44.005 \qquad (1)$$

The operating period limestone rates are shown in Table 4.5-1.

The hourly average air- and nitrogen-flow rates are shown in Figure 4.3-2 and the hourly synthesis gas rates are shown in Figure 4.3-3. Table 4.5-2 provides the air, nitrogen, and synthesis gas operating period flow rates. The synthesis gas rate was checked for all the operating periods using an oxygen balance around the synthesis gas combustor and found to be in excellent agreement with the synthesis gas combustor data for most of the operating periods.

It is estimated that about 1,000 lb/hr nitrogen from FI609 does not enter the process but is used to seal valves, pressurize/depressurize feed and ash lock hopper systems, and in the seals for the screw coolers. Values shown in Table 4.5-2 and Figure 4.3-2 assume that 1,000 lb/hr of nitrogen from FI609 does not enter the Transport Reactor. A small amount of nitrogen (~200 lb/hr) is added via FI6080 to the Transport Reactor through the coke breeze feed line to keep the line clear between periods of coke breeze feed. This is included in the feed nitrogen.

The steam rate to the reactor was determined from either FIC289, which measures the steam flow to the reactor J-leg, or FI204, which measures the total steam flow to the reactor. FI204 was used for TC06-1 through TC06-17 and FIC289 was used for TC06-18 to TC06-64. The choice was based on which instrument was reading above zero during the operating period. The hourly average steam rate is shown in Figure 4.3-9. Not much steam was fed to the reactor after hour 100.

The solids flow from the PCD can be determined from two different methods by using:

1. In situ particulate sampling data upstream of the PCD.

2. FD0530 weigh cell data.

The best measurement of the solids flow to the PCD is the in situ PCD inlet particulate determination. Using the synthesis gas-flow rate, the solids flow to the PCD can be determined since the PCD captures all of the solids.

The FD0530 weigh cell data can be used to determine the PCD solids flow only if both the FD0530 feeder and the FD0510 feeder (standpipe solids) are off, because FD0520 and FD0510 both feed into FD0530 and FD0530 feeds the sulfator (atmospheric fluidized-bed combustor, AFBC). This method assumes that the PCD solids level in the PCD and FD0502 screw cooler are constant, that is the PCD solids level is neither increasing nor decreasing. The results for the first two methods are compared in Figure 4.5-2. Rates for use in the operating period mass and energy balance were interpolated between the in situ measurements and weigh cell measurements. The interpolated rates used for the operating periods in mass and energy calculations are shown in Table 4.5-2.

The FD0530 weigh cell measurements had a large scatter. Occasionally there seemed to be a daily cycle to the variations in FD0520 flow. With the exception of four of the in situ samples, the in situ samples agreed with the weigh cell readings. For the first 700 hours of operation, the PCD fines rate was about 300 to 450 lb/hr. When the coal rate was decreased at about 700 hours, the PCD fines rate decreased to about 200 lb/hr. As the coal rate was increased at the end of TC06, the PCD fines rate slowly returned to 425 lb/hr.

Solids were regularly withdrawn from the reactor to control the standpipe level during TC06, so the combined rates of FD0520 and FD0510 could be determined using FD0530 weigh cell data. The FD0510 rate can be estimated by the difference between the sum of the combined rates and an interpolated FD0520 rate. The FD0510 rate was then correlated to the FD0206 feeder speed. The correlation is shown on Figure 4.5-3 and is:

$$\text{FD0510 rate (lb/hr)} = 74.639(\text{rpm}) + 77.77 \tag{2}$$

The FD0510 rate shows a lot of scatter and correlates poorly to the FD0206 feeder speed. The FD0510 rate varied between 50 and 350 lb/hr. The large variation is due to the scatter in the FD0520 rates and the use of interpolated FD0520 rates.

The FD0510 rates for the steady operating periods are shown in Table 4.5-2. Since FD0510 was usually not operated for an entire operating period, the values shown in Table 4.5-2 and used in the mass balances have been prorated down from the FD0510 rates determined, as if FD0510 had been operating continuously. The approximate time that it takes for the Transport Reactor circulating solids to reach a constant value (steady-state value) can be determined from the average FD510 rate and the initial reactor volume of solids. Key assumptions in this calculation are that the Transport Reactor circulating solids stay in the reactor and most of the PCD fines that go through FD0520 are "once through solids." The reactor then can be modeled as a constant-volume, well-mixed reactor. The starting solids in the Transport Reactor are about 6,000 lb of sand. The average FD0510 withdrawal rate was about 85 lb/hr. The Transport Reactor residence time constant is then about 71 hours. Three residence times (283 hours) result in 95-percent reactor turnover, which would have been achieved at hour 431. Four residence times (284 hours) result in 98-percent reactor turnover, which would have been reached at 504 hours. Using Figure 4.4-6, it is clear that the reactor had not reached steady compositions until at least after hour 600. Possible explanations for this imbalance are that the reactor solids rate was lower than 85 lb/hr or that more sand had been added to the reactor than 6,000 lb.

In GCT3 and GCT4, both the carbon balance and energy balance were off by 10 to 20 percent, and it was speculated that this was due to FD0210 weigh cell data reading about 15 percent too high. Using coal rates determined by FD0210 weigh cell data again produced a TC06 carbon balance that had 10 to 20 percent more carbon entering the Transport Reactor than exiting the Transport Reactor. The other large carbon flows (synthesis gas carbon flow and PCD solids carbon flow) are independently checked, so it is likely that the weigh cell coal rate is in error. The coal rate was then determined by a carbon balance using the coal carbon, PCD carbon, synthesis gas carbon, standpipe carbon, synthesis gas rate, PCD solids rate, the reactor solids rates, and the reactor carbon accumulation. The results of this calculation are shown in

Table 4.5-1, where the Transport Reactor carbon flows are listed for each operating period. The carbon balance coal-flow rate is about 80 percent of the FD0210 weigh cell coal-flow rate.

The carbon balance coal-flow rate and the air-to-coal ratio for the operating periods are shown in the plot in Figure 4.5-4. The carbon balance coal-flow rates for the operating periods are provided in Table 4.5-2. The coal rate increased from 4,600 to 5,000 lb/hr from the start of the run to hour 74 and was constant at about 5,000 lb/hr until the 4-week break. From hour 280 to hour 695 the coal rate was gradually increased from 4,000 to 4,500 lb/hr. The coal rate was decreased to about 3,300 lb/hr at hour 760. The coal rate was then increased from 3,300 to 5,000 lb/hr from hour 873 and hour 974. For the last two operating periods the coal rate was steady at about 5,000 lb/hr. The air-to-coal ratio was at about 3.5 for the first 55 hours of TC06 and from hour 55 to hour 760, the air-to-coal ratio was at 3.3 to 3.4. When the coal rate was decreased, the air-to-coal ratio increased to 3.6, and when the coal rate increased, the air-to-coal ratio returned to about 3.3. The air rate was controlled either manually or automatically to maintain a desired reactor temperature. Since the desired set point temperature did not change much during TC06, the air-to-coal ratio was constant during TC06.

The synthesis gas LHV compared to the coal rate is shown in the plot in Figure 4.5-5. The LHV increased with the coal rate. The nonair nitrogen rate was constant during TC06 and as the coal rate increases, the relative amount of nonair nitrogen to air nitrogen decreases, thus reducing the nitrogen in the synthesis gas. This of course increases the LHV.

Carbon conversion is defined as the percent fuel carbon that is gasified to CO, CO_2, CH_4, C_2H_6, and higher hydrocarbons. The carbon conversion is the measure of how much carbon is rejected by the gasifier with the PCD and reactor solids. This rejected carbon is typically burned in a less efficient combustor and results in a less efficient use of the fuel. The carbon conversion against the coal rate is shown in the plot in Figure 4.5-5. The carbon conversions for each operating period are provided in Table 4.5-1. The carbon conversion was between 95 and 99 percent and was a weak function of coal-feed rate. As the coal rate increased the carbon conversion slightly decreased.

Material balances are useful in checking the accuracy and consistency of the data obtained as well as determining periods of operation where the data is suitable for model development or commercial plant design. Material balances for each operating period are provided in Figure 4.5-6 showing the relative difference (relative error) of Transport Reactor feeds in minus products out divided by the feeds ({In-Out}/In) and the absolute difference (absolute error) of the feeds and the products (In-Out). The overall material balance was excellent, with most of the run within ±3.0 percent for the relative difference (±1500 lb/hr for the absolute difference). The first 220 hours had the worst material balance. The material balance improved from -6 to -4 percent in the periods before the 4-week break. The periods from the 4-week break to hour 670 show the best material balance with relative errors from 0.0 to -3.0 percent (0 to -1200 lb/hr). The two outliers are at hours 498 and 548 (TC06-32 and TC06-36). These two operating periods were during the operation of the recycle gas compressor. The recycle gas compressor was operated during only one other operating period, TC06-57 (hour 913), and had no effect on the mass balance. There was a slight negative bias for the remainder of the run, averaging about -2 percent relative error (-1000 lb/hr). If 500 lb/hr of steam were leaking into the reactor from hour 220 to the end of the run, the mass balance would bracket the 0-percent mass balance line.

The gas composition data in Section 4.3 have no effect on the overall mass balance. The solids compositions affect the mass balance through the coal rate determined by carbon balance. The main contributors to the material balance are the synthesis gas rate (21,000 to 30,000 lb/hr), air rate (11,000 to 17,000 lb/hr), nitrogen rate (5,500 to 7,300 lb/hr), and coal rate (3,500 to 5,100 lb/hr).

The relative split between the flow rates of solids collected by the PCD and removed from the standpipe through FD0510 are shown in the plot in Figure 4.5-7 and listed on Table 4.5-2. The split follows the same trends as the flow rates. About 80 percent of the solids are removed by the PCD at higher coal rates of 4,000 to 5,000 lb/hr and 70 percent of the solids are removed by the PCD at coal rates of 3,400 lb/hr. It would appear that lower coal rates generate slightly more coarse material than higher coal rates.

Test period nitrogen balances are shown in the plot in Figure 4.5-8 and listed in Table 4.5-3. Typical nitrogen flows for TC06-61 are shown in Table 4.5-4. The first two operating periods (TC06-1 and TC06-2) had excellent nitrogen balances. The next three operating periods (TC06-3 to TC06-5) had the worse nitrogen balance at -5-percent agreement (-500 lb/hr nitrogen). For these three periods the nitrogen analyzer was out of service and the synthesis gas nitrogen was estimated by difference. For the rest of the first 220 hours of operation the nitrogen balance was -2 to -3 percent (-200 to -300 lb/hr nitrogen). For the remainder of TC06 the nitrogen balances were between 0 and +2 percent (0 to +200 lb), except for a few operating periods. The two low points were at hours 498 and 548, when the recycle gas compressor was in operation. The high periods of up to 4-percent error were during the increase in coal rates. For most of TC06 the nitrogen balance was centered +2 percent (+200 lb/hr nitrogen). The nitrogen balance would have been perfect for most of the run if the amount of lost nitrogen was reduced by 1,100 lb/hr rather than 1,000 lb/hr. The nitrogen flows as shown in Table 4.5-4 are dominated by the air, nitrogen, and synthesis gas flow. None of the solids contributes significantly to the nitrogen balance. The use of the in situ H_2O data rather than the analyzer H_2O data improved the nitrogen balance.

Sulfur balances for all the TC06 operating periods are provided in Figure 4.5-9 and Table 4.5-5. The synthesis gas sulfur compounds were not directly measured, but estimated from syngas combustor SO_2 analyzer data and synthesis gas combustor flue gas flow. The sulfur balances are not good. For TC06, the sulfur balance was biased high by 20 to 60 percent (2 to 8 lb/hr). From hour 700 to the rest of TC06, the sulfur balance was consistently off by 5 lb/hr even through the swings in coal-feed rate. The consistent error of 5 lb/hr could indicate a consistent error in the SGC SO_2 measurements or the measurement of the coal sulfur. An increase of 40 percent in the SGC SO_2 measurements would close the sulfur balance. The sulfur mass balance is difficult to close due to the low sulfur content of the PRB coal and PCD fines.

With such large errors in the sulfur balances, it is difficult to determine the correct sulfur removal. There are three different methods to determine the sulfur removals:

1. From synthesis gas sulfur emissions (using the synthesis gas combustor flue gas rate and synthesis gas combustor flue gas SO_2 measurement) and the feed-sulfur rate (using the feed-coal rate and coal sulfur content). (Gas method.)

2. From PCD solids analysis (using PCD solids-flow rate and PCD solids sulfur content) and the feed-sulfur rate. (Solids method.)

3. From the gas analysis data and the PCD solids data. (Products method.)

The three sulfur removals are shown in the plot in Figure 4.5-10 and in Table 4.5-5. The sulfur in the fuel is an inaccurate measurement due to the multiplication of a very small number (coal sulfur) by a very large number (coal-feed rate). The low coal sulfur contents (0.25- to 0.35-weight-percent sulfur) increase the error in feed sulfur. The gaseous sulfur measurement is also the product of a small number (SGC SO_2) and a large number (SCG flue gas rate). However, the consistent error in the sulfur balance of 4 lb/hr is disturbing since it implies that the SGS SO_2 measurement is 40 percent lower than the actual measurement. This is because it is more accurate to measure gas-flow rates and compositions and these flows and compositions are measured continuously. The PCD fines sulfur rate may have inaccuracies in the very low sulfur in the PCD solids. There is no accumulation of sulfur-containing solids in the reactor during TC06 because the standpipe and FD0510 reactor samples contained very small amounts of sulfur. The gas method sulfur removal was between 30 and 75 percent for most of TC06, with most of the removals between 50 and 70 percent. The sulfur removals by the products and solids methods varied widely during TC06, from between 0 and 55 percent.

The synthesis gas combustor SO_2 concentration was used for the sulfur emissions shown in Table 4.5-5. The sulfur emissions based on the gas analyses are from 0.14 to 0.39 lb SO_2 per MBtu coal fed.

Operating periods hydrogen balances are provided in Figure 4.5-11 and Table 4.5-3 with typical values shown in Table 4.5-4. The coal and synthesis gas streams dominate the hydrogen balance, especially since very little steam was fed to the Transport Reactor during TC06. The best hydrogen balances were from hours 297 to 548 when the hydrogen balance was 0 to -5 percent (0 to -20 lb hydrogen per hour). For the first 200 hours, the hydrogen balance was low by -10 to -40 percent. From hours 550 to 840, the hydrogen balance decreased down to -25 percent then increased to -10 percent at the end of the run. This is probably due to the primary gas cooler (HX0202) steam leak, which leaked steam into the Transport Reactor during TC06. This steam leak got progressively worse during TC06. The coal rate increase seemed to improve the hydrogen balance. Using the in situ synthesis gas moisture measurements rather than the analyzer moisture measurements makes the hydrogen balance better for most of the operating periods. If about 360 lb/hr of steam (40 lb/hr hydrogen) were leaking into the reactor through HX0202 for the last 400 hours of TC06, the hydrogen balance would be nearly perfect.

Operating period oxygen balances are shown in Figure 4.5-12 and Table 4.5-3, with typical values provided in Table 4.5-4. The TC06 operating periods oxygen balance had a consistent low bias. The oxygen balance was usually low, from -3 to -13 percent (-200 to -600 lb/hr oxygen). This may be a result of the HX0202 steam leak. The oxygen balance was consistently off by about -500 lb/hr oxygen (equivalent to 560 lb/hr steam) from hour 640 to the end of the test. The oxygen balance would have been excellent if 560 lb/hr of steam was leaking into the reactor. Note the large oxygen contribution of the feed coal since PRB has a high oxygen content (moisture plus elemental oxygen). From hours 297 to 569, the oxygen balance was off by -250 lb/hr of oxygen (that is equivalent to 280 lb/hr steam). Using the in situ synthesis gas moisture measurements rather than the analyzer moisture measurements made the oxygen balance better for most of the operating periods.

Operating period calcium balances are provided in Figure 4.5-13 and Table 4.5-3, with typical values shown in Table 4.5-4. The PRB operation is characterized by low sorbent-feed rates because of low sulfur in the PRB coal. About half of the inlet calcium comes from fuel and half from sorbent. The calcium balances were mixed during TC06, with a calcium balance varying from a positive to negative bias. This is probably due to the low calcium flows in the system, the inaccuracies of the sorbent and coal feeder flows, and since the calcium flow is the result of multiplying a small number (calcium in the coal) by a large number (coal-flow rate). TC06 started with a positive calcium bias and then fell to a negative bias from hours 41 to 84 with a minimum of -20 percent at hour 55. The calcium balance was then positive from hours 91 to 336 with a maximum of +35 percent. There was then a long period of negative calcium balances from hours 354 to 896, with a minimum of -47 percent. From hours 913 to 960, the calcium balances were excellent with between +5 and -5 percent agreement. This was the period of increasing coal rate and was after the reactor reached a constant composition.

The PCD fines calcium is typically not totally calcined, as shown in Figure 4.4-10 where the calcium calcination was 70 to 90 percent. The level of sorbent limestone calcination can be calculated by a mass balance since the sorbent limestone and the coal calcium-feed rates are known. The sorbent limestone calcination calculation uses the assumption that the calcium in the coal ash has not recarbonated. Figure 4.5-14 shows the estimate of the limestone calcination for TC06 assuming that the calcium from the coal ash in the PCD solids is neglected. The limestone sorbent calcination varied from 55 to 90 percent and is usually less than the total calcium calcination. The poor calcium balance is probably responsible for the wide variations in the limestone calcination. Also shown in the plot in Figure 4.5-14 is the $CaCO_3$ calcination temperature calculated from the CO_2 partial pressure in the synthesis gas. Figure 4.3-15 of the GCT1 final report shows a plot of the CO_2 partial pressure for the $CaCO_3$-CaO-CO_2 system. The calcination temperature varied between 1,640 and 1,660°F, slightly below the mixing zone temperature of 1,700 to 1,800°F. If the $CaCO_3$ is at equilibrium at the mixing zone temperatures, it should all calcine to CaO and CO_2. As the CaO cools, thermodynamic equilibrium predicts that the CaO should recarbonate to $CaCO_3$ at the PCD temperatures of 700 to 750°F.

It can not be determined from the data whether the limestone calcined and then recarbonated as thermodynamics would predict or whether the limestone only partially calcined. It is probably the former since compound decomposition reactions (like limestone calcination) are fast and go quickly to completion. The recarbonation reaction is also fast, but is limited by the mass transfer of the CO_2 into the PCD fines particle. It is likely that the mass transfer prevents the solids sampled from FD0520 to be completely carbonated.

Figure 4.5-15 is a plot of TC06 sulfur emissions (expressed as lb SO_2 emitted per MBtu coal fed) and products method sulfur removal as a function of calcium to sulfur ratio (Ca/S), based on the coal and sorbent fed to the Transport Reactor. It would appear that the sulfur emissions are independent of the feed Ca/S when the feed Ca/S ratio is above 2.25. The sulfur emissions are based on the synthesis gas combustor SO_2 analyzer and are shown in Table 4.5-5. When the feed Ca/S ratios are below 2.25, the sulfur emissions are higher and the SO_2 removal is lower. Above a Ca/S ratio of 2.25, the sulfur removal and sulfur emissions are constant. Due to the poor sulfur and calcium balances, the actual trend might not be evident due to the errors in the data.

Figure 4.5-16 is a plot of TC06 sulfur emissions (expressed as lb SO_2 emitted per MBtu coal fed) and sulfur removal by products as a function of calcium to sulfur ratio (Ca/S) measured in the PCD solids samples from FD0520. The measured PCD solids Ca/S ratio is much higher than the feed Ca/S because the PRB coal has high calcium content. There does not appear to be any trend in PCD solids Ca/S with sulfur emissions. The results seen in Figure 4.5-16 demonstrate that when the PCD solids contain very little sulfur (high Ca/S), the SO_2 removals are low and the SO_2 emissions are high, which is reasonable by sulfur balance. The calcium sulfation is the reciprocal of the Ca/S ratio based on the PCD fines solids.

Operating periods SiO_2 balances are shown in Figure 4.5-17, with typical values shown in Table 4.5-4. Table 4.5-3 provides the results of the SiO_2 balances for all of the operating periods. The SiO_2 balance mainly reflects the coal, reactor draw-off rate, and PCD solids rate, since the limestone sorbent typically had only 2.5 percent SiO_2. The SiO_2 balance is similar to the calcium balance since both are dominated by the coal and PCD solids rates and compositions. The SiO_2 balances were generally very poor, with the SiO_2 balances less than -50 percent for the most of the first 600 hours of operation. The SiO_2 balance was always biased negative (that is, there were more SiO_2 leaving the reactor than entering). The SiO_2 balance seemed to improve as startup sand was purged from the reactor. The poor SiO_2 balance might be due to the reactor accumulation/depletion term, which is difficult to estimate. The best SiO_2 balances were between hours 926 and 960, the same periods as when the CaO balance was the best and the reactor was at the steady-state solids composition.

The gas-flow rates were self-consistent as shown by the good overall mass balance, which is dominated by the gas-flow rate measurements and was -3 to + 0.0 percent for the last 800 hours of TC06. The nitrogen balance was also excellent at (0.0 to +2.0 percent) for the last 800 hours. The sulfur balance was poor with a high bias at +50 percent (+5-lb sulfur per hour). The hydrogen and oxygen balances were of by about -10 percent, which could be explained by a steam leak from HX0202 into the transport rector. The calcium balance was not good (- 50 to +30 percent), usually with a negative bias. The SiO_2 balance had a high negative bias from -200 to 0 percent. Both the calcium and SiO_2 balances seemed to improve as the reactor reached the steady-state solids composition (possibly due to the difficulty in estimating reactor solids accumulation).

The Transport Reactor energy balance for TC06 is shown in Figure 4.5-18, with standard conditions chosen to be 1.0 atmosphere pressure and 80°F temperature. Table 4.5-6 breaks down the individual components of the energy balance for each operating period. The "energy in" consists of the coal, air, and steam fed to the Transport Reactor. The nitrogen and sorbent fed to the reactor were considered to be at the standard conditions (80°F) and hence have zero enthalpy. The "energy out" consisted of the synthesis gas and PCD solids. The lower heating value of the coal and PCD solids was used in order to be consistent with the lower heating value of the synthesis gas. While the reactor solids sampled from FD0510 flow had no latent heat, there was a small amount of sensible heat in the FD0510 solids. The energy of the synthesis gas was determined at the Transport Reactor cyclone exit. The sensible enthalpy of the synthesis gas was determined by overall gas heat capacity from the synthesis gas compositions and the individual gas heat capacities. The synthesis gas and PCD solids energy consists of both latent and sensible heat. The heat loss in the reactor was estimated to be 1.5 x 10^6 Btu/hr, which was measured during a previous Transport Reactor combustion test.

For most of the test runs, the TC06 energy balance was biased low by -0 to -5 percent (-0 to -2.0 MBtu/hr). This is a much better energy balance than previous runs when the coal-flow rates were based on the FD0210 weigh cell data. An increase in coal-flow rates by 4 percent would put most of the operating periods in energy balance. The carbon balance would then be off by 4 percent. The first five operating periods had very low balances of -10 to -20 percent, then after 73 hours, were from -3 to -5 percent out of balance. The first two operating periods after the restart (TC06-15 and TC06-16) had high energy balances of +5 percent. The final 500 hours of TC06 had very stable energy balances at around -4 percent (-1.5 MBtu/hr). This energy imbalance of -1.5 MBtu per hour would be eliminated if the Transport Reactor were assumed to be adiabatic. Any steam that was leaked into the process from HX0202 would also improve the energy balance (and the oxygen and hydrogen balances). The equivalent amount of steam required to account for 1.5 MBtu/hr is 1,250 lb/hr of steam, which seems excessive. The best estimate would be that about 560 lb/hr steam leaked into the reactor unmeasured (from the oxygen balance) and the Transport Reactor heat loss was about 0.8 MBtu/hr rather than 1.5 MBtu/hr. The addition of the loop seal increased the solids circulation rate, which should increase the average standpipe temperature. The higher standpipe temperature should have increased the heat loss of the standpipe.

Gasification efficiency is defined as the percent of the coal energy that is converted to potentially useful synthesis gas energy. Two types of gasification efficiencies are used: cold gas efficiency and hot gas efficiency. The cold gas efficiency is the amount of coal energy that is available to a gas turbine as latent heat of the synthesis gas.

Similar to sulfur removal, the cold gas efficiency can be calculated at least three different ways, since the energy balance is off by up to about 4 percent, and each result could be different. If there were a perfect energy balance, all three calculations would produce the same result. Three calculation methods for cold gasification consistent with the three methods of sulfur removal were performed.

1. Based on the coal feed heat (coal latent heat) and the latent heat of the synthesis gas, this method assumes that the coal feed heat and the synthesis gas latent heat are correct. (Gas method.)

2. Based on the feed heat (coal latent heat) and the latent heat of the synthesis gas determined by a Transport Reactor energy balance, not the gas method, this method assumes that the synthesis gas latent heat is incorrect. (Solids method.)

3. Based on the coal feed heat determined by Transport Reactor energy balance and the synthesis gas sensible heat, this assumes that the coal feed is error. (Products method.)

The cold gas gasification efficiencies for the three calculation methods are shown in the plot in Figure 4.5-19. For all of the operating periods, the products method is between the solids and gas methods. The gas method is higher than the solids for each operating period when the energy balance has a negative error, which is all but two of the operating periods. Since the energy balance is good, all three methods are usually within 5 percent of each other. Only the products method is listed on Table 4.5-6 because the products method is probably the most accurate since it does not use the coal rate determined by carbon balance. The products analysis cold gas gasification efficiencies were between 58 to 65 percent.

The hot gasification efficiency is the amount of coal energy that is available to a gas turbine plus a heat recovery steam generator. The hot gas efficiency counts both the latent and sensible heat of the synthesis gas. Similar to the cold gasification efficiency and the sulfur removal, the hot gas efficiency can be calculated at least three different ways. Since the energy balance is off by up to -4 percent, each efficiency will be different. The three calculation methods for hot gasification are identical with the three methods of cold gasification efficiency calculation except for the inclusion of the synthesis gas sensible heat into the hot gasification efficiency.

The hot gasification efficiency assumes that the sensible heat of the synthesis gas can be recovered in a heat recovery steam generator, so the hot gasification efficiency is always higher than the cold gasification efficiency. The three gasification calculation methods are shown in the plot in Figure 4.5-20 and the products method given in Table 4.5-6.

For all of the operating periods, the products method is essentially equal to the solids method. This is because the amount of inlet coal heat is about the same as the total synthesis gas heat, and it makes little difference whether the synthesis gas heat or the coal heat is corrected. The gas method is higher than the solids and products methods except for when the energy balance has a negative error (only two of the operating periods). Since the energy balance is good, all three methods are usually within 5 percent of each other. The products method hot gasification efficiencies were from 91 to 96 percent. These high efficiencies are a result of the low PCD fines carbon content and low PCD fines rates. As with the cold gasification efficiencies, the hot gasification efficiency by-products should be more accurate than the hot gasification efficiencies by the gas and solids. It is possible to obtain higher than 100-percent gasification efficiencies because they are based on the feed coal heat, not the total feed heat. Greater than 100-percent gasification efficiencies imply that the sum of the steam and air input heat is greater than the heat loss and PCD solids heat, which is unlikely except at very high carbon conversions. The first five gas methods are over 110 percent, and are clearly in error.

Two main sources of losses in efficiency are the reactor heat loss and the latent heat of the PCD solids. The reactor heat loss of 1.5 x 10^6 Btu/hr is about 4 percent of the feed coal energy, while the total energy of the PCD solids was about 4.5 percent of the feed coal energy. The heat loss percentage will decrease as the reactor size is increased. While the Transport Reactor does not recover the latent heat of the PCD solids, this latent heat could be recovered in a combustor.

The heat of the PCD solids can be decreased by decreasing both the PCD solids carbon content (heating value) and the PCD solids rate.

Gasification efficiencies can be calculated from the adiabatic nitrogen-corrected gas heating values that are shown in Section 4.3. The adiabatic nitrogen-corrected cold gasification efficiencies shown in the plot in Figure 4.5-21 and the products method-corrected cold gasification efficiencies are listed in Table 4.5-6 for all of the operating periods. Only the cold gasification efficiencies based on the products are provided in Table 4.5-6 because they are the most representative of the actual gasification efficiencies. The products method adiabatic nitrogen-corrected cold gasification efficiencies were from 72 to 76 percent for TC06. The adiabatic nitrogen-correction increases the cold gasification efficiencies by about 8 percent for most of the operating periods. The adiabatic nitrogen correction does not increase the hot gasification efficiency because the deleted nitrogen lowers the synthesis gas sensible heat and increases the synthesis gas latent heat. Both changes effectively cancel each other out.

Table 4.5-1

Carbon Rates

Operating Period	Average Relative Hours	Carbon In (Feed)			Carbon Out (Products)					Carbon Conversion %
		Coal[1] lb/hr	Sorbent lb/hr	Total lb/hr	Syngas lb/hr	Standpipe[2] lb/hr	PCD Solids lb/hr	Accumulation lb/hr	Total lb/hr	
TC06-1	21	2,651	24	2,676	2,524	1.3	150	0.92	2,676	95.2
TC06-2	29	2,513	12	2,526	2,411	0.5	114	0.01	2,526	95.9
TC06-3	34	2,536	12	2,549	2,447	0.5	101	0.42	2,549	96.5
TC06-4	41	2,651	12	2,663	2,569	0.5	94	-0.01	2,663	96.9
TC06-5	55	2,594	12	2,605	2,502	0.2	103	0.03	2,605	96.5
TC06-6	74	2,798	17	2,816	2,689	0.2	126	-0.02	2,816	96.1
TC06-7	84	2,764	17	2,782	2,649	0.2	132	0.05	2,782	95.8
TC06-8	91	2,880	23	2,903	2,773	0.3	130	-0.03	2,903	96.3
TC06-9	124	2,715	23	2,738	2,604	0.3	134	-0.02	2,738	95.9
TC06-10	146	2,874	23	2,897	2,786	0.2	111	-0.02	2,897	96.9
TC06-11	153	2,866	23	2,889	2,781	0.1	108	0.02	2,889	97.0
TC06-12	189	2,721	24	2,745	2,619	0.2	126	0.07	2,745	96.2
TC06-13	199	2,817	25	2,842	2,727	0.2	114	0.03	2,842	96.8
TC06-14	222	2,751	25	2,775	2,653	0.4	122	-0.08	2,775	96.5
TC06-15	234	2,620	16	2,637	2,522	0.8	114	0.11	2,637	96.3
TC06-16	244	2,717	19	2,736	2,617	0.6	118	0.07	2,736	96.3
TC06-17	255	2,766	22	2,788	2,658	0.2	130	0.00	2,788	96.1
TC06-18	270	2,062	19	2,081	1,941	3.1	136	0.74	2,081	94.1
TC06-19	280	2,305	19	2,325	2,178	5.8	141	-0.38	2,325	94.5
TC06-20	297	2,292	19	2,311	2,156	1.0	154	0.30	2,311	94.1
TC06-21	309	2,279	19	2,298	2,135	0.7	162	0.04	2,298	93.7
TC06-22	336	2,421	19	2,440	2,263	0.3	177	0.04	2,440	93.5
TC06-23	354	2,495	19	2,514	2,349	0.3	165	0.03	2,514	94.1
TC06-24	374	2,459	15	2,474	2,307	0.5	166	0.13	2,474	93.8
TC06-25	390	2,517	15	2,532	2,365	0.6	166	-0.08	2,532	94.0
TC06-26	420	2,488	15	2,504	2,376	0.4	127	-0.01	2,504	95.5
TC06-27	449	2,472	17	2,490	2,373	0.8	116	-0.08	2,490	96.0
TC06-28	470	2,457	15	2,472	2,358	0.6	113	0.35	2,472	96.0
TC06-29	477	2,465	15	2,480	2,356	0.6	124	0.07	2,480	95.6
TC06-30	486	2,527	15	2,542	2,413	0.5	129	0.10	2,542	95.5
TC06-31	494	2,468	15	2,484	2,358	0.5	125	0.10	2,484	95.5
TC06-32	498	2,377	15	2,392	2,269	0.5	123	0.16	2,392	95.4

Notes:
1. Coal carbon determined by carbon balance.
2. Standpipe carbon flow intermittent. Rate shown is average FD0510 rate during operating period.

Table 4.5-1

Carbon Rates (continued)

Operating Period	Average Relative Hours	Carbon In (Feed)			Carbon Out (Products)					Carbon Conversion %
		Coal[1] lb/hr	Sorbent lb/hr	Total lb/hr	Syngas lb/hr	Standpipe[2] lb/hr	PCD Solids lb/hr	Accumulation lb/hr	Total lb/hr	
TC06-33	505	2,574	15	2,589	2,469	0.5	120	-0.02	2,589	95.9
TC06-34	520	2,544	15	2,559	2,439	0.4	119	0.05	2,559	95.9
TC06-35	534	2,495	15	2,510	2,392	0.4	117	0.06	2,510	95.9
TC06-36	548	2,627	15	2,642	2,509	0.4	133	-0.20	2,642	95.5
TC06-37	555	2,594	15	2,609	2,475	0.4	135	-0.22	2,609	95.4
TC06-38	569	2,517	15	2,532	2,389	0.4	143	-0.06	2,532	94.9
TC06-39	586	2,498	15	2,514	2,371	0.4	143	0.01	2,514	94.9
TC06-40	608	2,476	15	2,491	2,380	0.3	111	-0.04	2,491	96.1
TC06-41	643	2,621	15	2,636	2,552	0.2	84	0.00	2,636	97.4
TC06-42	648	2,486	12	2,498	2,411	0.2	87	0.05	2,498	97.0
TC06-43	670	2,597	15	2,613	2,517	0.1	96	0.00	2,613	96.9
TC06-44	695	2,601	15	2,616	2,506	0.1	110	0.00	2,616	96.3
TC06-45	711	2,406	15	2,422	2,303	0.2	119	0.00	2,422	95.7
TC06-46	719	2,578	14	2,592	2,480	0.9	112	0.28	2,592	96.2
TC06-47	760	1,944	15	1,959	1,896	0.8	62	-0.07	1,959	97.5
TC06-48	787	2,021	15	2,036	1,984	0.3	51	0.01	2,036	98.2
TC06-49	818	1,971	15	1,986	1,942	0.2	43	0.02	1,986	98.6
TC06-50	829	1,889	15	1,904	1,867	0.1	37	-0.01	1,904	98.8
TC06-51	840	1,931	8	1,939	1,898	0.1	41	-0.01	1,939	98.3
TC06-52	850	1,884	15	1,899	1,867	0.1	32	0.00	1,899	99.1
TC06-53	859	1,874	15	1,889	1,866	0.1	23	0.02	1,889	99.6
TC06-54	873	2,094	15	2,109	2,081	0.2	28	-0.02	2,109	99.4
TC06-55	896	2,312	15	2,327	2,286	0.3	41	0.03	2,327	98.9
TC06-56	908	2,375	15	2,390	2,343	0.2	47	-0.05	2,390	98.7
TC06-57	913	2,415	15	2,430	2,380	0.1	50	0.03	2,430	98.5
TC06-58	926	2,403	15	2,418	2,350	0.2	68	-0.01	2,418	97.8
TC06-59	941	2,510	15	2,525	2,438	0.2	87	-0.02	2,525	97.1
TC06-60	949	2,625	15	2,640	2,542	0.2	97	0.02	2,640	96.9
TC06-61	960	2,675	15	2,690	2,574	0.2	116	0.02	2,690	96.2
TC06-62	974	2,870	15	2,885	2,746	0.6	138	-0.02	2,885	95.7
TC06-63	998	2,938	15	2,953	2,795	0.9	157	0.01	2,953	95.1
TC06-64	1,016	2,930	15	2,945	2,785	0.3	160	0.04	2,945	95.1

Notes:

1. Coal carbon determined by carbon balance.
2. Standpipe carbon flow intermittent. Rate shown is average rate during operating period.

Table 4.5-2

Feed Rates, Product Rates, and Mass Balance

		Feeds (In)						Products (Out)							
Operating Period	Average Relative Hours	Coal[4] lb/hr	Sorbent FD0220 lb/hr	Air FI205 lb/hr	Nitrogen FI609[1] lb/hr	Steam FI204[2] lb/hr	Total lb/hr	Syngas FI465 lb/hr	PCD Solids FD0520 lb/hr	SP Solids FD0510[3] lb/hr	Reactor Accumulation lb/hr	Total lb/hr	In - Out lb/hr	(In- Out)/In %	PCD Solids/ Total Solids Out %
TC06-1	21	4,759	195	16,201	6,697	125	27,976	28,356	363	80	56	28,855	-879	-3.1	82
TC06-2	29	4,542	100	15,773	6,684	146	27,245	27,784	344	86	1	28,216	-971	-3.6	80
TC06-3	34	4,600	100	16,627	6,117	431	27,875	29,080	338	80	69	29,567	-1,691	-6.1	81
TC06-4	41	4,789	98	16,865	6,308	466	28,527	29,532	350	98	-3	29,977	-1,450	-5.1	78
TC06-5	55	4,633	98	16,721	6,313	681	28,446	29,426	377	88	10	29,900	-1,454	-5.1	81
TC06-6	74	4,926	150	16,868	6,494	329	28,767	29,686	417	99	-11	30,191	-1,424	-5.0	81
TC06-7	84	4,837	152	16,726	6,598	203	28,515	29,321	430	80	20	29,851	-1,336	-4.7	84
TC06-8	91	5,047	198	17,252	6,740	182	29,420	30,154	427	104	-13	30,672	-1,253	-4.3	80
TC06-9	124	4,826	198	16,690	6,777	12	28,504	29,207	414	98	-9	29,711	-1,207	-4.2	81
TC06-10	146	5,106	198	17,259	6,961	22	29,546	30,206	398	98	-9	30,692	-1,146	-3.9	80
TC06-11	153	5,082	198	17,163	6,950	19	29,412	30,009	395	81	14	30,499	-1,088	-3.7	83
TC06-12	189	4,816	206	16,233	6,730	4	27,989	28,487	332	88	32	28,939	-951	-3.4	79
TC06-13	199	4,976	210	16,799	6,613	6	28,605	29,276	396	90	11	29,774	-1,169	-4.1	81
TC06-14	222	4,824	210	16,575	6,753	1	28,363	28,916	396	113	-23	29,403	-1,040	-3.7	78
TC06-15	234	4,635	142	14,830	7,254	0	26,862	26,589	395	80	12	27,075	-213	-0.8	83
TC06-16	244	4,781	164	15,226	6,750	149	27,070	26,858	394	79	8	27,340	-270	-1.0	83
TC06-17	255	4,699	193	15,775	6,774	28	27,470	27,328	385	79	2	27,793	-323	-1.2	83
TC06-18	270	3,715	164	12,391	7,776	6	24,053	23,618	364	79	19	24,080	-27	-0.1	82
TC06-19	280	4,129	164	13,318	7,046	18	24,675	24,328	356	79	-5	24,758	-83	-0.3	82
TC06-20	297	4,071	164	13,213	6,623	80	24,151	23,760	378	80	24	24,242	-91	-0.4	83
TC06-21	309	4,053	164	13,265	6,749	16	24,247	23,969	394	80	5	24,448	-201	-0.8	83
TC06-22	336	4,226	164	13,625	6,474	29	24,518	24,226	429	80	9	24,744	-226	-0.9	84
TC06-23	354	4,261	164	14,080	6,546	61	25,112	24,772	453	80	8	25,313	-201	-0.8	85
TC06-24	374	4,277	129	13,880	6,441	37	24,764	24,490	451	80	23	25,043	-279	-1.1	85
TC06-25	390	4,395	130	14,093	6,502	15	25,134	24,694	441	110	-15	25,231	-97	-0.4	80
TC06-26	420	4,307	131	14,461	6,497	8	25,404	24,986	418	102	-3	25,503	-99	-0.4	80
TC06-27	449	4,333	148	14,464	6,426	27	25,399	25,051	348	104	-10	25,493	-94	-0.4	77
TC06-28	470	4,388	131	14,573	6,573	9	25,674	25,354	369	80	50	25,852	-178	-0.7	82
TC06-29	477	4,372	130	14,286	6,465	9	25,262	25,032	381	80	11	25,504	-243	-1.0	83
TC06-30	486	4,477	131	14,613	6,402	9	25,631	25,384	398	80	14	25,877	-245	-1.0	83
TC06-31	494	4,374	131	14,525	6,512	10	25,552	25,308	413	80	15	25,816	-264	-1.0	84
TC06-32	498	4,213	129	14,080	6,620	10	25,052	25,240	420	80	26	25,765	-713	-2.8	84

Notes:
1. Nitrogen feed rate reduced by 1,000 pounds per hour to account for losses in feed systems and seals.
2. Steam rate taken from FI204 for TC06-1 to TC06-17 and from FIC289 for TC06-18 to TC06-64.
3. FD0510 was not always operated during an entire test period. FD0510 flow rates shown have been prorated to account for the actual time of FD0510 operation.
4. Coal Rate by carbon balance.

Table 4.5-2

Feed Rates, Product Rates, and Mass Balance (continued)

		Feeds (In)						Products (Out)							
Operating Period	Average Relative Hours	Coal[4] lb/hr	Sorbent FD0220 lb/hr	Air FI205 lb/hr	Nitrogen FI609[1] lb/hr	Steam FIC298[2] lb/hr	Total lb/hr	Syngas FI465 lb/hr	PCD Solids FD0520 lb/hr	SP Solids FD0510[3] lb/hr	Reactor Accumulation lb/hr	Total lb/hr	In - Out lb/hr	(In- Out)/In %	PCD Solids/ Total Solids Out %
TC06-33	505	4,579	129	14,914	6,386	10	26,018	25,660	432	80	-3	26,168	-150	-0.6	84
TC06-34	520	4,575	130	14,969	6,623	8	26,305	25,936	417	79	9	26,440	-135	-0.5	84
TC06-35	534	4,319	129	14,767	6,626	79	25,920	25,553	398	79	11	26,041	-121	-0.5	83
TC06-36	548	4,588	129	14,999	6,491	56	26,263	26,668	435	79	-41	27,141	-878	-3.3	85
TC06-37	555	4,529	131	14,957	6,332	8	25,957	25,692	425	79	-46	26,150	-193	-0.7	84
TC06-38	569	4,389	129	14,456	6,447	12	25,433	25,212	411	83	-13	25,693	-260	-1.0	83
TC06-39	586	4,359	131	14,416	6,451	6	25,364	25,127	417	99	4	25,647	-283	-1.1	81
TC06-40	608	4,329	131	14,578	6,333	9	25,379	25,439	399	103	-11	25,929	-550	-2.2	80
TC06-41	643	4,572	129	15,449	6,413	82	26,645	26,691	350	80	-1	27,120	-475	-1.8	81
TC06-42	648	4,338	103	14,520	6,341	123	25,425	25,486	349	79	23	25,937	-512	-2.0	81
TC06-43	670	4,561	131	15,228	6,402	10	26,332	26,374	345	81	1	26,801	-468	-1.8	81
TC06-44	695	4,538	131	15,231	6,389	12	26,301	26,429	430	85	-1	26,944	-643	-2.4	83
TC06-45	711	4,176	130	14,353	6,786	12	25,457	25,608	395	82	-1	26,084	-627	-2.5	83
TC06-46	719	4,464	122	14,923	6,261	10	25,780	25,959	375	80	26	26,439	-659	-2.6	82
TC06-47	760	3,358	129	12,176	6,200	11	21,875	22,001	271	100	-8	22,365	-490	-2.2	73
TC06-48	787	3,483	129	12,450	6,028	8	22,098	22,284	245	98	4	22,632	-533	-2.4	71
TC06-49	818	3,410	129	12,213	6,106	9	21,867	22,018	225	103	14	22,360	-493	-2.3	69
TC06-50	829	3,286	129	12,032	6,167	5	21,618	21,843	218	103	-7	22,157	-539	-2.5	68
TC06-51	840	3,373	67	12,027	6,297	11	21,776	21,741	211	97	-8	22,041	-265	-1.2	68
TC06-52	850	3,299	129	11,841	6,297	6	21,573	21,331	204	107	1	21,643	-70	-0.3	66
TC06-53	859	3,289	129	12,129	6,115	7	21,669	21,456	200	91	26	21,772	-103	-0.5	69
TC06-54	873	3,648	129	13,161	6,047	20	23,005	23,013	205	109	-13	23,314	-308	-1.3	65
TC06-55	896	4,020	130	14,009	5,866	15	24,040	24,166	217	91	11	24,486	-446	-1.9	70
TC06-56	908	4,159	130	14,309	5,938	18	24,555	24,370	224	115	-25	24,685	-130	-0.5	66
TC06-57	913	4,226	131	14,471	5,933	37	24,797	24,906	231	80	19	25,237	-440	-1.8	74
TC06-58	926	4,180	130	14,087	5,577	87	24,061	24,021	253	109	-6	24,377	-316	-1.3	70
TC06-59	941	4,339	130	14,419	5,571	59	24,518	24,578	276	100	-9	24,945	-427	-1.7	73
TC06-60	949	4,525	129	15,055	5,715	16	25,440	25,582	286	79	8	25,956	-515	-2.0	78
TC06-61	960	4,601	130	15,167	5,902	28	25,828	25,913	307	88	7	26,315	-487	-1.9	78
TC06-62	974	4,954	128	16,099	6,129	22	27,332	27,491	332	89	-2	27,910	-578	-2.1	79
TC06-63	998	5,027	130	16,392	6,043	29	27,621	27,579	377	94	1	28,051	-430	-1.6	80
TC06-64	1016	5,014	131	16,124	6,019	13	27,301	27,376	411	88	11	27,887	-585	-2.1	82

Notes:

1. Nitrogen feed rate reduced by 1,000 pounds per hour to account for losses in feed systems and seals.
2. Steam rate taken from FI204 for TC06-1 to TC06-17 and from FIC289 for TC06-18 to TC06-64.
3. FD0510 was not always operated during an entire test period. FD0510 flow rates shown have been prorated to account for the actual time of FD0510 operation.
4. Coal Rate by carbon balance.

Table 4.5-3

Nitrogen, Hydrogen, Oxygen, and Silicon Mass Balances

Operating Period	Average Relative Hours	Nitrogen[1]		Hydrogen		Oxygen		Calcium		SiO_2	
		(In- Out) In %	In - Out lb/hr	(In- Out) In %	In - Out lb/hr	(In- Out) In %	In - Out lb/hr	(In- Out) In %	In - Out lb/hr	(In- Out) In %	In - Out lb/hr
TC06-1	21	1.1	218	-62.1	-203	-16.0	-886	61.6	63	-169.7	-149
TC06-2	29	0.5	98	-63.5	-201	-16.1	-859	30.7	22	-124.9	-97
TC06-3	34	-4.8	-908	-48.7	-172	-9.7	-566	12.9	9	-159.2	-130
TC06-4	41	-3.4	-661	-45.6	-168	-10.2	-608	-3.6	-3	-88.0	-74
TC06-5	55	-4.9	-938	-32.5	-124	-5.2	-317	-19.0	-14	-99.1	-78
TC06-6	74	-2.4	-471	-21.8	-79	-13.0	-770	-5.3	-5	-72.4	-59
TC06-7	84	-1.7	-326	-25.8	-88	-14.0	-806	-11.6	-10	-86.1	-68
TC06-8	91	-1.7	-336	-23.2	-82	-12.8	-763	4.8	5	-66.3	-56
TC06-9	124	-3.0	-594	-21.1	-67	-8.7	-489	5.6	6	-62.9	-51
TC06-10	146	-2.6	-520	-16.1	-54	-9.2	-535	11.8	12	-53.8	-51
TC06-11	153	-2.3	-467	-15.7	-53	-8.8	-511	13.3	14	-56.0	-55
TC06-12	189	-2.7	-516	-12.4	-39	-6.6	-359	34.4	36	-40.8	-40
TC06-13	199	-3.2	-624	-12.7	-42	-7.5	-424	13.3	14	-35.1	-37
TC06-14	222	-2.0	-386	-19.6	-62	-9.2	-513	21.8	23	-58.4	-52
TC06-15	234	2.7	512	-0.2	-1	-10.0	-506	11.3	10	-102.8	-85
TC06-16	244	2.3	427	3.8	12	-9.5	-508	18.7	17	-89.2	-78
TC06-17	255	2.4	453	-11.7	-37	-8.9	-475	25.5	26	-64.6	-61
TC06-18	270	2.3	391	-8.7	-21	-7.9	-331	10.0	8	-104.9	-73
TC06-19	280	1.7	289	-6.5	-18	-7.5	-343	15.4	13	-53.7	-38
TC06-20	297	1.1	177	-1.9	-5	-4.5	-204	10.0	9	-100.2	-66
TC06-21	309	0.4	75	-2.8	-8	-4.9	-221	9.3	8	-78.8	-52
TC06-22	336	0.2	29	-1.3	-4	-3.3	-154	1.7	2	-84.6	-58
TC06-23	354	0.5	82	-0.5	-1	-2.9	-138	-5.7	-5	-144.3	-82
TC06-24	374	0.1	14	0.7	2	-3.7	-177	-23.0	-18	-135.2	-84
TC06-25	390	1.1	196	-0.5	-1	-4.3	-205	-14.5	-11	-107.1	-74
TC06-26	420	1.3	232	-1.9	-5	-4.0	-196	-19.8	-15	-130.6	-84
TC06-27	449	1.0	177	-4.2	-12	-4.5	-220	3.7	3	-60.5	-45
TC06-28	470	0.7	115	-3.4	-10	-4.8	-237	-19.4	-15	-106.5	-77
TC06-29	477	0.5	85	-5.6	-16	-5.8	-281	-14.9	-12	-80.6	-55
TC06-30	486	0.4	71	-4.9	-15	-5.4	-269	-19.4	-15	-82.5	-57
TC06-31	494	0.4	63	-4.8	-14	-5.3	-257	-26.6	-21	-95.4	-65
TC06-32	498	-1.6	-282	-3.8	-11	-7.0	-330	-35.4	-27	-116.1	-76
TC06-33	505	1.0	170	-4.2	-13	-5.3	-266	-28.2	-23	-81.8	-59

Notes:

1. Nitrogen feed rate reduced by 1,000 pounds per hour to account for losses in feed systems and seals.

Table 4.5-3

Nitrogen, Hydrogen, Oxygen, and Silicon Mass Balances (continued)

Operating Period	Average Relative Hours	Nitrogen[1]		Hydrogen		Oxygen		Calcium		SiO_2	
		(In- Out) In	In - Out	(In- Out) In	In - Out	(In- Out) In	In - Out	(In- Out) In	In - Out	(In- Out) In	In - Out
		%	lb/hr	%	lb/hr	%	lb/hr	%	lb/hr	%	lb/hr
TC06-34	520	0.7	119	-3.1	-9	-4.6	-233	-20.0	-16	-91.9	-69
TC06-35	534	1.1	189	-3.4	-10	-3.7	-186	-13.1	-10	-109.6	-71
TC06-36	548	-2.7	-490	-3.2	-10	-6.4	-328	-2.7	-2	-65.3	-46
TC06-37	555	0.9	166	-7.0	-21	-6.0	-301	0.9	1	-58.2	-39
TC06-38	569	1.1	197	-9.9	-29	-7.5	-367	-9.5	-7	-71.9	-46
TC06-39	586	1.2	209	-9.7	-28	-7.6	-372	-18.0	-14	-94.1	-61
TC06-40	608	0.8	145	-13.2	-38	-8.9	-434	-15.2	-12	-100.9	-67
TC06-41	643	1.6	292	-16.1	-50	-10.3	-542	-8.3	-7	-30.2	-28
TC06-42	648	1.5	258	-15.1	-45	-10.1	-504	-29.6	-21	-48.4	-42
TC06-43	670	1.3	237	-15.3	-46	-10.4	-532	-4.9	-4	-50.4	-37
TC06-44	695	0.9	160	-14.0	-42	-9.7	-494	-23.5	-19	-53.5	-49
TC06-45	711	1.1	191	-19.7	-54	-11.7	-563	-14.8	-11	-40.5	-35
TC06-46	719	1.5	265	-20.7	-61	-12.6	-630	-21.3	-16	-30.2	-29
TC06-47	760	1.7	266	-24.1	-54	-12.9	-518	-20.3	-14	-21.1	-16
TC06-48	787	0.9	141	-18.2	-42	-11.1	-458	-18.8	-13	-34.2	-23
TC06-49	818	1.2	182	-18.3	-41	-11.4	-459	-26.2	-18	-66.3	-36
TC06-50	829	0.8	129	-19.7	-43	-11.9	-469	-20.9	-14	-51.1	-27
TC06-51	840	2.9	445	-21.3	-48	-12.8	-508	-45.9	-23	-52.3	-28
TC06-52	850	4.0	619	-21.9	-48	-12.5	-491	-15.7	-11	-62.6	-33
TC06-53	859	3.6	558	-21.7	-48	-11.5	-457	-21.9	-15	-67.3	-36
TC06-54	873	2.3	375	-21.4	-52	-11.7	-511	-7.3	-5	-47.5	-27
TC06-55	896	1.0	168	-16.7	-45	-10.0	-466	-2.3	-2	-29.1	-20
TC06-56	908	2.0	344	-11.1	-31	-7.8	-372	6.6	5	-10.2	-8
TC06-57	913	0.3	59	-10.8	-31	-7.7	-376	4.2	3	-10.6	-9
TC06-58	926	0.7	113	-8.2	-23	-6.5	-311	3.2	2	-8.3	-7
TC06-59	941	0.5	82	-10.2	-30	-7.9	-388	1.4	1	-2.0	-2
TC06-60	949	0.4	61	-13.4	-40	-8.9	-451	3.4	3	-1.6	-1
TC06-61	960	0.7	122	-13.2	-40	-9.4	-483	0.3	0	-8.5	-7
TC06-62	974	0.1	27	-12.5	-41	-9.4	-514	9.2	8	-3.8	-3
TC06-63	998	0.9	162	-9.7	-32	-8.2	-457	-0.7	-1	-19.8	-17
TC06-64	1016	0.3	47	-12.1	-40	-8.8	-481	-15.4	-13	-26.4	-23

Notes:

1. Nitrogen feed rate reduced by 1,000 pounds per hour to account for losses in feed systems and seals.

Table 4.5-4

Typical Component Mass Balances

	Nitrogen[1]	Hydrogen	Oxygen	Calcium	SiO_2
Operating Period	TC06-61	TC06-61	TC06-61	TC06-61	TC06-61
Date	9/21/01	9/21/01	9/21/01	9/21/01	9/21/01
Time Start	09:30	09:30	09:30	09:30	09:30
Time End	21:00	21:00	21:00	21:00	21:00
Fuel	PRB	PRB	PRB	PRB	PRB
Sorbent	OH LS	OH LS	OH LS	OH LS	OH LS
Mixing Zone Temperature, °F	1,450	1,450	1,450	1,450	1,450
Pressure, psig	230	230	230	230	230
In, pounds/hr					
Fuel	29	281	1,406	41	75
Sorbent			60	39	3
Air	11,420	22	3,642		
Nitrogen	6,095				
Steam		3	25		
Total	17,545	305	5,133	81	78
Out, pounds/hr					
Synthesis Gas	17,422	344	5,573		
PCD Solids	1	1	37	54	52
Reactor			6	24	30
Accumulation			1	2	3
Total	17,423	346	5,616	80	84
(In-Out)/In, %	0.7%	-13.2%	-9.4%	0.3%	-8.5%
(In-Out), pounds per hour	122	-40	-483	0	-7

1. Feed nitrogen decreased by 1,000 pounds per hour.

Table 4.5-5

Sulfur Balances

	Average	Feeds (In)	Products (Out)							Sulfur Removal			Sulfur
Operating Period	Relative Hours	Coal lb/hr	Syngas lb/hr	PCD Solids lb/hr	Reactor lb/hr	Accumulation lb/hr	Total lb/hr	In - Out lb/hr	(In- Out)/In %	Gas %	Products %	Solids %	Emissions lb SO_2/MBtu
TC06-1	21	13.5	5.6	3.9	0.1	0.1	9.6	3.9	28.8	59	41	29	0.25
TC06-2	29	12.0	6.2	4.1	0.1	0.0	10.3	1.6	13.5	48	40	34	0.29
TC06-3	34	12.3	8.3	3.8	0.0	0.0	12.2	0.2	1.4	32	31	30	0.39
TC06-4	41	12.6	7.4	2.7	0.0	0.0	10.0	2.5	20.2	42	27	21	0.33
TC06-5	55	11.4	7.6	1.1	0.0	0.0	8.7	2.7	23.7	34	13	10	0.35
TC06-6	74	12.1	6.6	1.7	0.0	0.0	8.3	3.8	31.2	45	20	14	0.29
TC06-7	84	12.2	5.8	1.9	0.1	0.0	7.8	4.4	36.2	52	25	16	0.25
TC06-8	91	13.1	5.9	1.9	0.1	0.0	7.8	5.2	39.9	55	24	14	0.25
TC06-9	124	13.8	6.6	2.0	0.0	0.0	8.5	5.3	38.3	53	23	14	0.29
TC06-10	146	14.8	6.9	2.0	0.0	0.0	8.9	5.9	40.1	54	23	13	0.29
TC06-11	153	14.7	6.9	2.1	0.0	0.0	9.1	5.7	38.5	53	24	15	0.29
TC06-12	189	13.8	6.1	3.3	0.0	0.0	9.5	4.3	31.2	55	35	24	0.27
TC06-13	199	14.0	6.3	2.8	0.0	0.0	9.1	4.9	35.2	55	30	20	0.27
TC06-14	222	14.5	5.8	2.3	0.0	0.0	8.0	6.4	44.4	60	28	16	0.26
TC06-15	234	13.9	5.2	1.2	0.0	0.0	6.4	7.5	53.7	63	19	9	0.24
TC06-16	244	14.4	6.1	1.2	0.0	0.0	7.3	7.1	49.4	58	16	8	0.27
TC06-17	255	14.9	7.0	1.0	0.0	0.0	8.0	6.9	46.5	53	12	7	0.32
TC06-18	270	11.1	3.1	1.4	0.0	0.0	4.6	6.6	59.1	72	31	13	0.18
TC06-19	280	11.9	2.9	1.7	0.0	0.0	4.7	7.2	60.8	75	37	14	0.15
TC06-20	297	11.1	2.8	2.3	0.0	0.0	5.2	5.9	53.3	75	45	21	0.15
TC06-21	309	10.7	4.4	2.8	0.0	0.0	7.2	3.4	32.3	59	39	26	0.23
TC06-22	336	10.8	4.3	3.3	0.0	0.0	7.6	3.2	30.0	61	44	30	0.21
TC06-23	354	10.0	4.3	3.2	0.1	0.0	7.6	2.4	23.8	57	42	32	0.22
TC06-24	374	11.0	3.0	3.7	0.1	0.0	6.8	4.2	38.1	73	56	34	0.15
TC06-25	390	11.2	4.0	4.1	0.1	0.0	8.2	3.0	26.7	64	51	37	0.20
TC06-26	420	10.1	2.8	2.4	0.1	0.0	5.3	4.9	47.9	73	46	24	0.14
TC06-27	449	10.0	3.8	2.2	0.1	0.0	6.0	4.0	39.7	62	36	22	0.19
TC06-28	470	10.3	3.3	1.3	0.0	0.0	4.7	5.6	54.4	68	29	13	0.16
TC06-29	477	10.5	4.1	1.7	0.0	0.0	5.8	4.7	44.7	61	29	16	0.20
TC06-30	486	10.9	3.9	1.9	0.0	0.0	5.8	5.0	46.4	64	32	17	0.19
TC06-31	494	10.7	4.3	1.8	0.0	0.0	6.1	4.6	42.7	60	29	17	0.21
TC06-32	498	10.4	4.0	1.8	0.0	0.0	5.8	4.5	43.7	61	30	17	0.20

Notes:

1. Synthesis gas sulfur emissions determined from synthesis gas combustor SO_2 analyzer.

Table 4.5-5

Sulfur Balances (continued)

		Feeds (In)	Products (Out)							Sulfur Removal			Sulfur
Operating Period	Average Relative Hours	Coal lb/hr	Syngas lb/hr	PCD Solids lb/hr	Reactor lb/hr	Accumulation lb/hr	Total lb/hr	In - Out lb/hr	(In- Out)/In %	Gas %	Products %	Solids %	Emissions lb SO_2/MBtu
TC06-33	505	11.5	3.3	1.7	0.0	0.0	5.0	6.6	56.9	72	34	15	0.15
TC06-34	520	11.8	3.9	1.6	0.0	0.0	5.4	6.4	53.9	67	29	13	0.18
TC06-35	534	10.4	3.2	2.6	0.0	0.0	5.8	4.6	44.0	69	45	25	0.16
TC06-36	548	11.5	3.7	1.9	0.0	0.0	5.6	5.8	50.8	67	34	17	0.17
TC06-37	555	11.5	3.3	1.4	0.0	0.0	4.7	6.8	59.0	71	30	12	0.15
TC06-38	569	11.4	4.5	1.9	0.0	0.0	6.3	5.1	44.7	61	29	16	0.22
TC06-39	586	11.0	4.9	3.0	0.0	0.0	7.9	3.1	27.9	56	38	28	0.24
TC06-40	608	10.4	5.0	3.0	0.0	0.0	7.9	2.4	23.5	52	37	29	0.24
TC06-41	643	11.0	6.3	1.5	0.0	0.0	7.9	3.1	27.9	42	19	14	0.30
TC06-42	648	10.5	5.4	1.7	0.1	0.0	7.2	3.3	31.2	48	24	16	0.27
TC06-43	670	11.4	4.5	2.5	0.1	0.0	7.0	4.4	38.2	61	36	22	0.21
TC06-44	695	11.5	4.9	1.7	0.1	0.0	6.7	4.8	41.6	58	26	15	0.23
TC06-45	711	10.8	4.4	1.8	0.1	0.0	6.2	4.6	42.2	60	29	17	0.22
TC06-46	719	11.6	3.8	1.7	0.1	0.0	5.7	5.9	51.1	67	31	15	0.18
TC06-47	760	8.8	3.4	1.0	0.2	0.0	4.6	4.2	47.8	62	24	12	0.21
TC06-48	787	9.6	3.6	1.0	0.1	0.0	4.7	4.9	51.0	63	22	11	0.22
TC06-49	818	9.1	3.5	0.9	0.1	0.0	4.5	4.6	50.4	62	21	10	0.22
TC06-50	829	8.6	2.9	0.7	0.1	0.0	3.7	5.0	57.5	67	20	8	0.18
TC06-51	840	8.7	3.9	0.8	0.1	0.0	4.7	4.0	45.6	56	16	9	0.24
TC06-52	850	8.4	2.8	0.6	0.1	0.0	3.5	4.9	57.9	67	19	7	0.18
TC06-53	859	8.2	3.1	0.5	0.1	0.0	3.7	4.5	54.7	63	14	6	0.20
TC06-54	873	8.9	3.8	0.6	0.1	0.0	4.6	4.3	48.6	57	14	7	0.22
TC06-55	896	9.5	3.7	0.5	0.1	0.0	4.3	5.1	54.1	61	12	5	0.20
TC06-56	908	9.6	4.1	0.8	0.1	0.0	5.0	4.6	48.2	57	16	8	0.21
TC06-57	913	9.8	4.3	0.9	0.1	0.0	5.3	4.6	46.4	57	18	9	0.21
TC06-58	926	10.2	4.0	2.0	0.1	0.0	6.0	4.2	41.0	61	33	19	0.20
TC06-59	941	10.5	3.6	2.3	0.1	0.0	6.0	4.5	43.0	66	39	22	0.18
TC06-60	949	10.7	2.8	2.1	0.1	0.0	5.0	5.7	53.4	74	42	19	0.13
TC06-61	960	10.5	4.0	1.7	0.1	0.0	5.8	4.7	44.4	62	30	17	0.19
TC06-62	974	11.0	4.0	2.2	0.1	0.0	6.4	4.7	42.3	63	36	20	0.17
TC06-63	998	11.7	4.3	2.8	0.1	0.0	7.1	4.6	39.4	64	39	24	0.18
TC06-64	1016	11.8	4.0	3.3	0.0	0.0	7.3	4.5	37.8	66	45	28	0.17

Notes:

1. Synthesis gas sulfur emissions determined from synthesis gas combustor SO_2 analyzer.

Table 4.5-6

Energy Balances

		Feeds (In)				Products (Out)							Efficiency		
													Raw[2]		Corrected[2,4]
Operating Period	Average Relative Hours	Coal 10^6 Btu/hr	Air 10^6 Btu/hr	Steam 10^6 Btu/hr	Total 10^6 Btu/hr	Syngas 10^6 Btu/hr	PCD Solids 10^6 Btu/hr	Reactor Solids 10^6 Btu/hr	Heat Loss 10^6 Btu/hr	Total 10^6 Btu/hr	In - Out 10^6 Btu/hr	(In- Out)/In %	Cold %	Hot %	Cold %
TC06-1	21	41.3	1.0	0.0	42.4	45.3	2.2	0.04	1.5	49.1	-6.7	-15.7	64.6	94.4	73.7
TC06-2	29	38.4	1.0	0.1	39.4	43.6	1.8	0.04	1.5	47.0	-7.6	-19.2	64.4	94.9	74.1
TC06-3	34	39.2	1.0	0.6	40.8	44.2	1.7	0.04	1.5	47.4	-6.6	-16.2	64.2	96.5	74.4
TC06-4	41	41.0	1.1	0.6	42.7	46.1	1.5	0.05	1.5	49.2	-6.5	-15.2	65.3	97.1	75.3
TC06-5	55	39.8	1.0	0.9	41.8	44.3	1.5	0.04	1.5	47.4	-5.7	-13.5	64.8	97.5	75.6
TC06-6	74	42.8	1.1	0.4	44.3	42.1	2.0	0.05	1.5	45.6	-1.4	-3.1	62.2	95.5	72.6
TC06-7	84	42.2	1.1	0.3	43.6	41.6	2.1	0.04	1.5	45.2	-1.7	-3.9	61.5	94.8	71.8
TC06-8	91	44.1	1.1	0.2	45.4	43.6	2.1	0.05	1.5	47.2	-1.8	-3.9	62.4	95.1	72.6
TC06-9	124	41.8	1.1	0.0	42.9	41.5	2.0	0.05	1.5	45.1	-2.2	-5.1	61.8	94.4	72.7
TC06-10	146	43.8	1.1	0.0	44.9	43.8	1.8	0.05	1.5	47.1	-2.2	-4.8	63.0	95.3	73.8
TC06-11	153	43.5	1.1	0.0	44.6	43.8	1.8	0.04	1.5	47.1	-2.5	-5.6	63.3	95.2	74.1
TC06-12	189	42.3	1.0	0.0	43.3	41.4	2.0	0.04	1.5	44.9	-1.6	-3.7	62.9	94.3	73.9
TC06-13	199	43.7	1.1	0.0	44.7	42.9	1.9	0.04	1.5	46.3	-1.5	-3.5	63.2	94.8	73.9
TC06-14	222	42.6	1.0	0.0	43.6	42.1	1.9	0.06	1.5	45.6	-2.0	-4.6	62.6	94.6	73.3
TC06-15	234	41.5	1.0	0.0	42.4	36.8	1.8	0.04	1.5	40.2	2.2	5.3	62.5	93.9	73.8
TC06-16	244	42.7	1.0	0.2	43.9	38.1	1.8	0.04	1.5	41.4	2.4	5.6	62.6	94.4	73.2
TC06-17	255	41.8	1.0	0.0	42.8	41.3	1.9	0.04	1.5	44.7	-1.9	-4.4	64.0	94.5	74.2
TC06-18	270	32.6	0.8	0.0	33.4	29.6	2.1	0.04	1.5	33.2	0.2	0.5	58.4	91.3	72.3
TC06-19	280	36.2	0.8	0.0	37.1	33.5	2.2	0.04	1.5	37.2	-0.1	-0.4	60.8	92.1	72.7
TC06-20	297	35.8	0.8	0.1	36.7	32.9	2.4	0.04	1.5	36.9	-0.2	-0.4	61.3	91.5	72.8
TC06-21	309	35.4	0.8	0.0	36.3	32.7	2.6	0.04	1.5	36.8	-0.5	-1.4	60.2	91.0	72.0
TC06-22	336	37.6	0.9	0.0	38.5	35.3	2.7	0.04	1.5	39.5	-1.1	-2.8	62.1	91.3	73.0
TC06-23	354	38.0	0.9	0.1	39.0	36.6	2.6	0.04	1.5	40.7	-1.7	-4.5	62.7	92.0	73.4
TC06-24	374	37.8	0.8	0.0	38.6	35.7	2.5	0.04	1.5	39.7	-1.0	-2.7	62.2	91.9	73.1
TC06-25	390	38.9	0.9	0.0	39.9	36.6	2.5	0.05	1.5	40.7	-0.8	-2.0	62.8	92.2	73.4
TC06-26	420	38.7	0.9	0.0	39.6	36.9	2.1	0.05	1.5	40.6	-0.9	-2.4	62.9	93.2	73.6
TC06-27	449	38.3	0.9	0.0	39.3	36.9	1.8	0.05	1.5	40.3	-1.0	-2.6	63.4	93.8	74.2
TC06-28	470	38.4	0.9	0.0	39.4	36.7	1.8	0.04	1.5	40.0	-0.6	-1.5	62.7	93.9	73.9
TC06-29	477	38.2	0.9	0.0	39.1	36.6	2.0	0.04	1.5	40.2	-1.0	-2.6	63.1	93.4	74.0
TC06-30	486	39.0	0.9	0.0	40.0	37.6	2.1	0.04	1.5	41.2	-1.2	-3.0	63.2	93.4	73.8
TC06-31	494	38.1	0.9	0.0	39.0	36.7	2.0	0.04	1.5	40.3	-1.2	-3.2	62.5	93.3	73.5
TC06-32	498	36.7	0.9	0.0	37.6	35.0	2.0	0.04	1.5	38.6	-1.0	-2.6	60.9	93.0	72.9

Notes:
1. Nitrogen and sorbent assumed to enter the system at ambient temperature and therefore have zero enthalpy.
2. Using coal inlet heat determined from energy balance.
3. Reference conditions are 80°F and 14.7 psia.
4. Correction is to assume that only air nitrogen is in the synthesis gas and that the reactor is adiabatic.

Table 4.5-6

Energy Balances (continued)

Operating Period	Average Relative Hours	Feeds (In)				Products (Out)					In - Out	(In- Out)/In	Efficiency		
													Raw[2]		Corrected[2,4]
		Coal 10^6 Btu/hr	Air 10^6 Btu/hr	Steam 10^6 Btu/hr	Total 10^6 Btu/hr	Syngas 10^6 Btu/hr	PCD Solids 10^6 Btu/hr	Reactor Solids 10^6 Btu/hr	Heat Loss 10^6 Btu/hr	Total 10^6 Btu/hr	10^6 Btu/hr	%	Cold %	Hot %	Cold %
TC06-33	505	39.8	1.0	0.0	40.8	38.5	2.0	0.04	1.5	42.0	-1.2	-3.1	63.6	93.8	74.0
TC06-34	520	39.9	0.9	0.0	40.9	38.1	1.9	0.04	1.5	41.5	-0.6	-1.5	63.1	93.9	73.9
TC06-35	534	38.3	0.9	0.0	39.2	37.4	2.0	0.04	1.5	40.9	-1.7	-4.4	62.8	93.6	73.7
TC06-36	548	40.5	1.0	0.0	41.5	39.4	2.2	0.04	1.5	43.1	-1.6	-3.9	62.4	93.4	73.4
TC06-37	555	40.1	1.0	0.0	41.1	38.9	2.2	0.04	1.5	42.6	-1.5	-3.7	63.4	93.4	73.5
TC06-38	569	39.0	0.9	0.0	40.0	37.5	2.2	0.04	1.5	41.3	-1.3	-3.3	62.7	92.9	73.1
TC06-39	586	38.7	0.9	0.0	39.6	37.1	2.2	0.05	1.5	40.8	-1.2	-3.1	62.6	92.9	73.1
TC06-40	608	38.3	0.9	0.0	39.3	37.4	1.8	0.05	1.5	40.8	-1.5	-3.9	62.8	93.9	73.5
TC06-41	643	40.5	1.0	0.1	41.6	40.2	1.4	0.04	1.5	43.1	-1.5	-3.6	64.3	95.6	74.6
TC06-42	648	38.4	0.9	0.0	39.4	37.9	1.4	0.04	1.5	40.8	-1.5	-3.7	64.1	95.0	74.7
TC06-43	670	40.1	1.0	0.0	41.1	39.5	1.5	0.04	1.5	42.6	-1.5	-3.7	63.8	95.0	74.2
TC06-44	695	40.1	1.0	0.0	41.0	39.3	1.8	0.04	1.5	42.6	-1.6	-3.9	63.2	94.3	73.6
TC06-45	711	37.0	0.9	0.0	37.9	36.1	1.9	0.04	1.5	39.6	-1.7	-4.4	61.4	93.3	72.7
TC06-46	719	39.7	1.0	0.0	40.6	39.0	1.8	0.04	1.5	42.4	-1.8	-4.3	63.5	94.2	73.6
TC06-47	760	30.0	0.7	0.0	30.8	29.6	1.1	0.05	1.5	32.2	-1.4	-4.5	60.6	94.1	73.6
TC06-48	787	31.0	0.8	0.0	31.8	30.8	0.9	0.05	1.5	33.2	-1.5	-4.6	62.0	95.0	74.8
TC06-49	818	30.3	0.7	0.0	31.1	30.1	0.7	0.05	1.5	32.4	-1.4	-4.4	61.9	95.2	75.1
TC06-50	829	29.1	0.7	0.0	29.8	28.8	0.6	0.05	1.5	31.0	-1.2	-4.1	60.7	95.1	74.6
TC06-51	840	29.8	0.7	0.0	30.5	29.6	0.7	0.05	1.5	31.9	-1.4	-4.4	61.7	95.2	75.0
TC06-52	850	29.1	0.7	0.0	29.8	29.0	0.5	0.05	1.5	31.1	-1.3	-4.2	61.8	95.5	75.2
TC06-53	859	29.0	0.7	0.0	29.7	29.1	0.4	0.04	1.5	31.0	-1.3	-4.4	61.4	95.9	74.6
TC06-54	873	32.2	0.8	0.0	33.1	32.5	0.5	0.05	1.5	34.5	-1.5	-4.5	63.0	96.3	75.1
TC06-55	896	35.5	0.9	0.0	36.5	35.8	0.7	0.04	1.5	38.0	-1.6	-4.4	64.5	96.4	75.7
TC06-56	908	36.8	0.9	0.0	37.7	36.7	0.8	0.06	1.5	39.0	-1.4	-3.6	64.6	96.3	75.3
TC06-57	913	37.4	0.9	0.0	38.3	37.3	0.8	0.04	1.5	39.7	-1.3	-3.5	64.8	96.4	75.8
TC06-58	926	37.0	0.9	0.1	38.0	36.9	1.1	0.05	1.5	39.6	-1.6	-4.2	65.0	95.6	75.4
TC06-59	941	38.6	0.9	0.1	39.5	38.3	1.3	0.05	1.5	41.2	-1.6	-4.1	65.2	95.2	75.1
TC06-60	949	40.3	0.9	0.0	41.3	40.0	1.5	0.04	1.5	43.0	-1.7	-4.2	65.1	95.0	74.8
TC06-61	960	41.1	0.9	0.0	42.1	40.5	1.7	0.04	1.5	43.7	-1.7	-4.0	64.7	94.6	74.3
TC06-62	974	44.1	1.0	0.0	45.1	43.2	2.0	0.04	1.5	46.8	-1.6	-3.6	64.8	94.5	74.1
TC06-63	998	45.3	1.0	0.0	46.3	43.9	2.3	0.05	1.5	47.7	-1.4	-3.1	64.7	94.1	73.6
TC06-64	1,016	45.1	1.0	0.0	46.1	44.0	2.4	0.04	1.5	47.9	-1.8	-3.8	65.1	93.8	73.9

Notes:
1. Nitrogen and sorbent assumed to enter the system at ambient temperature and therefore have zero enthalpy.
2. Using coal inlet heat determined from energy balance.
3. Reference conditions are 80°F and 14.7 psia.
4. Correction is to assume that only air nitrogen is in the synthesis gas and that the reactor is adiabatic.

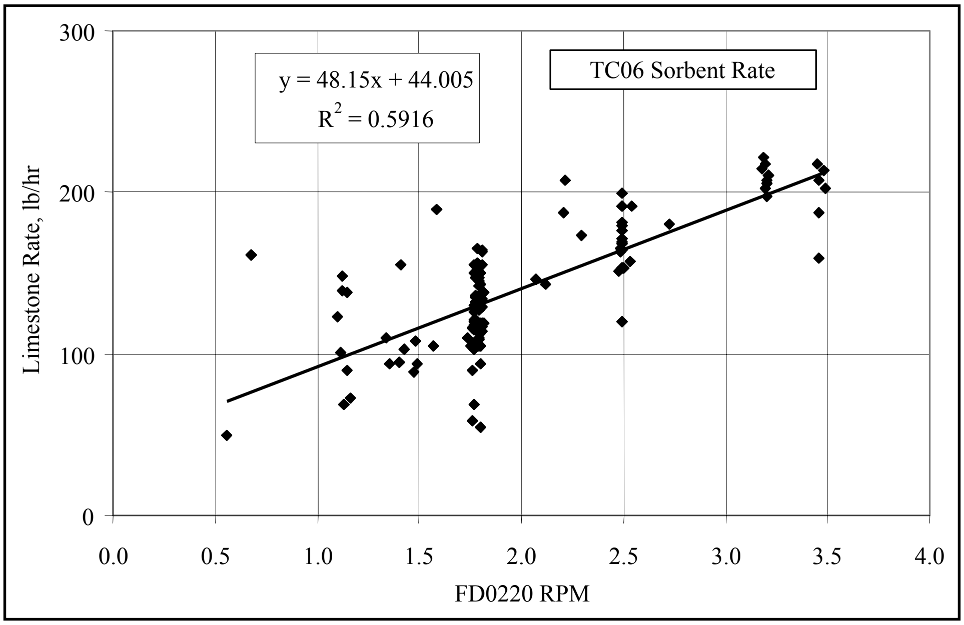

Figure 4.5-1 Sorbent Feeder Correlation

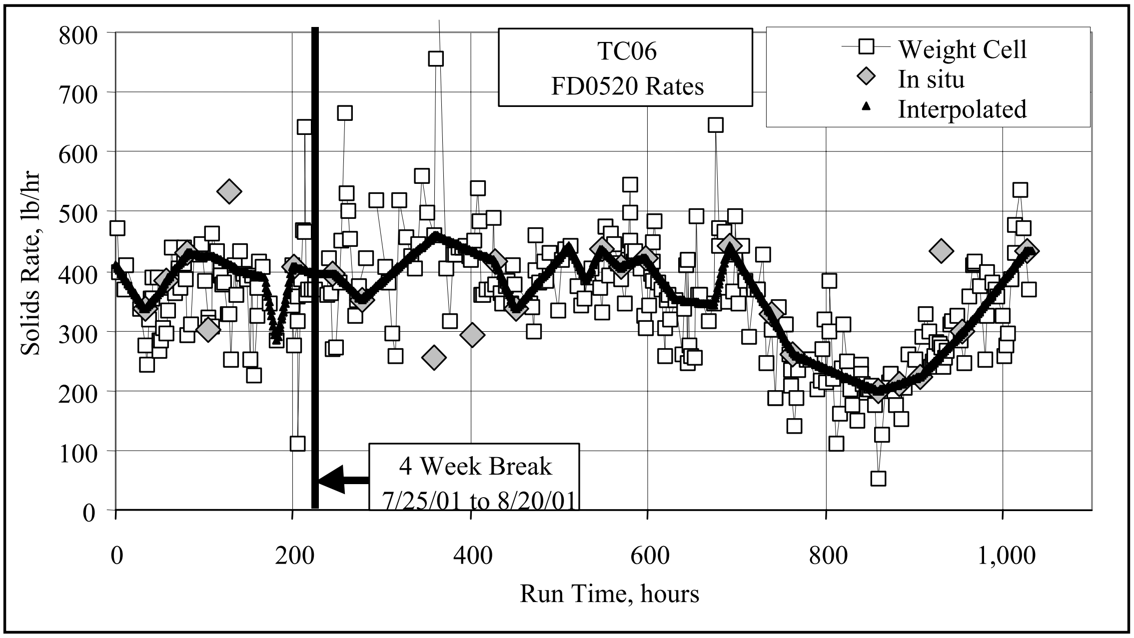

Figure 4.5-2 PCD Fines Rate

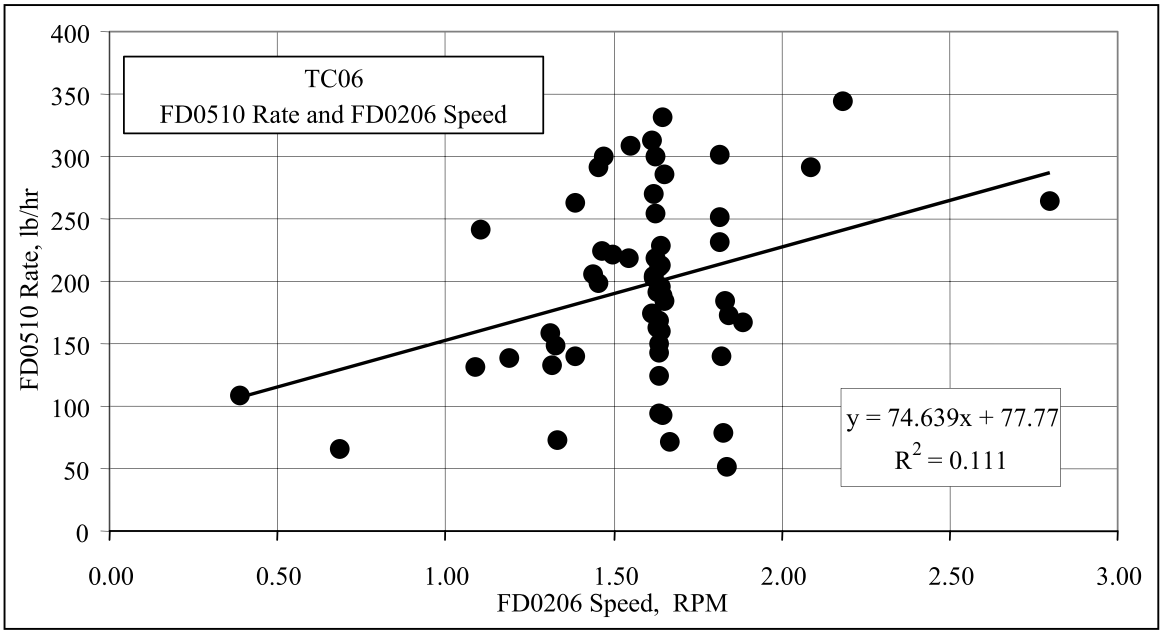

Figure 4.5-3 FD0510 Rate Correlation

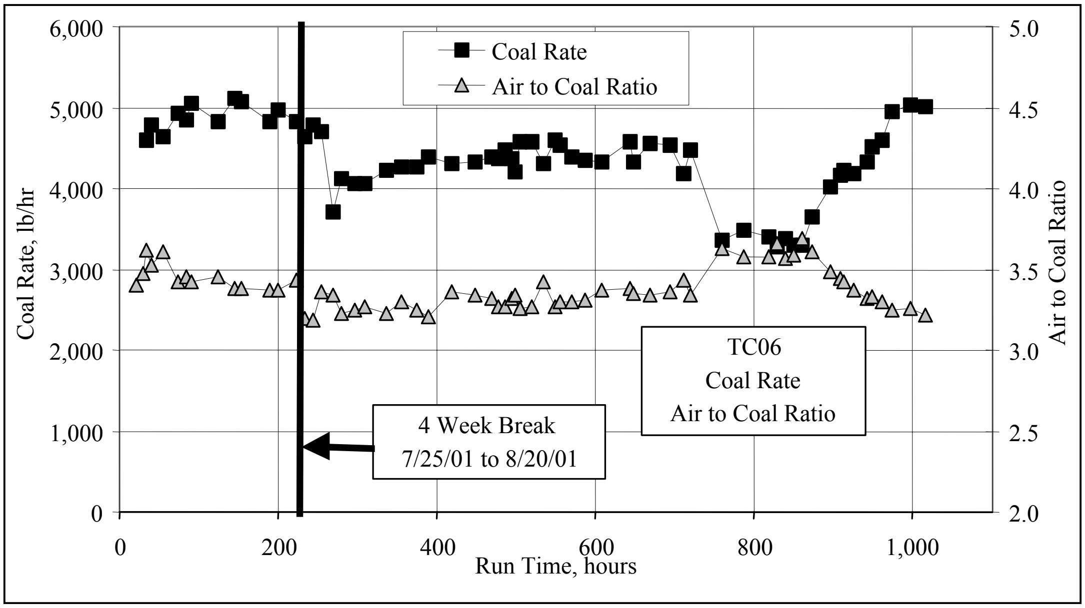

Figure 4.5-4 Coal and Air-to-Coal Ratio

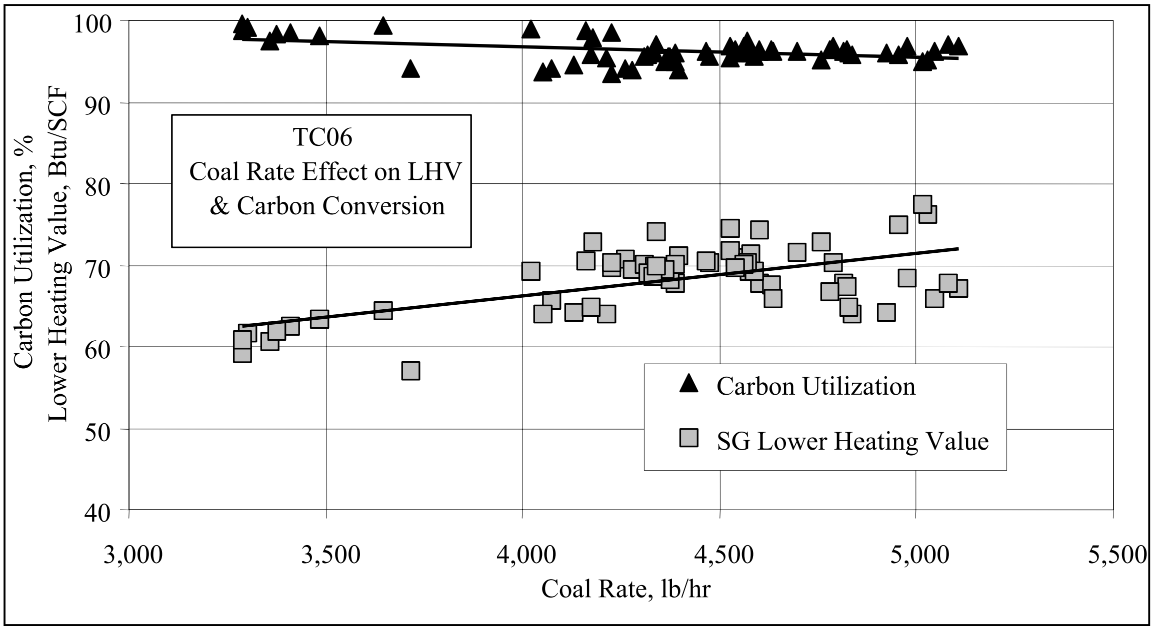

Figure 4.5-5 Effect of Coal Rate on LHV and Carbon Conversion

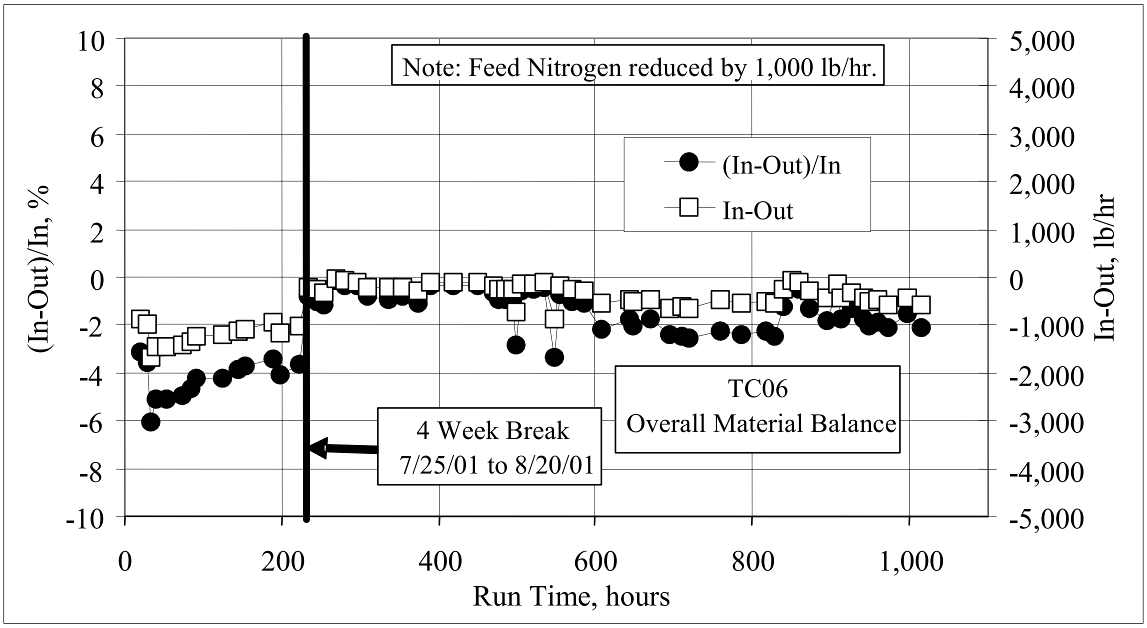

Figure 4.5-6 Overall Material Balance

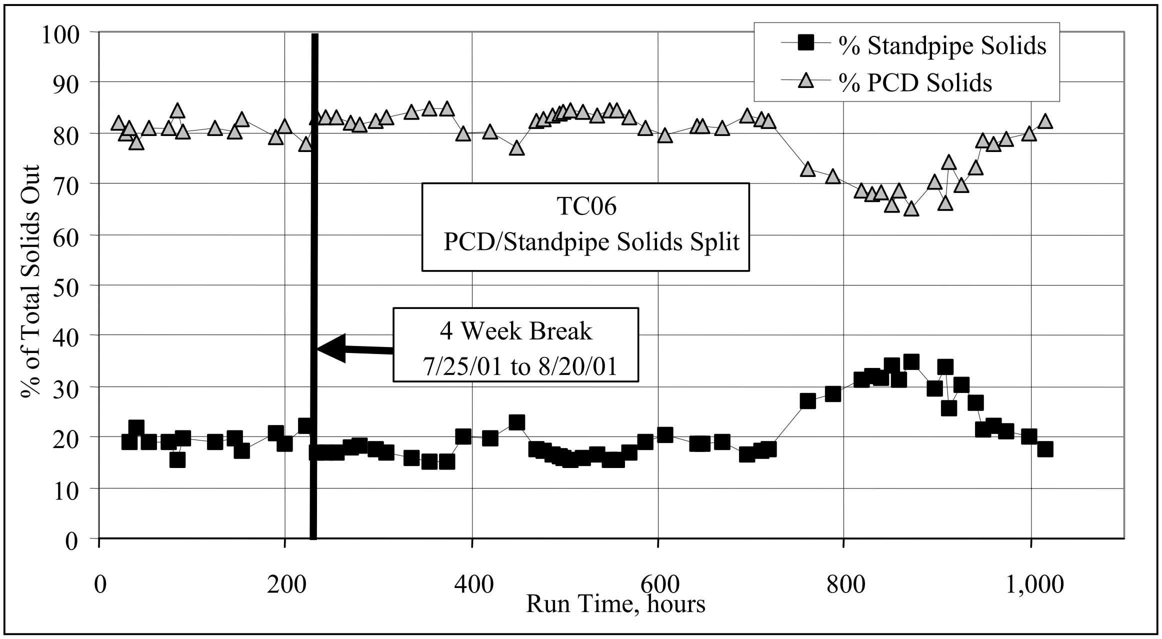

Figure 4.5-7 Reactor Products Flow Split

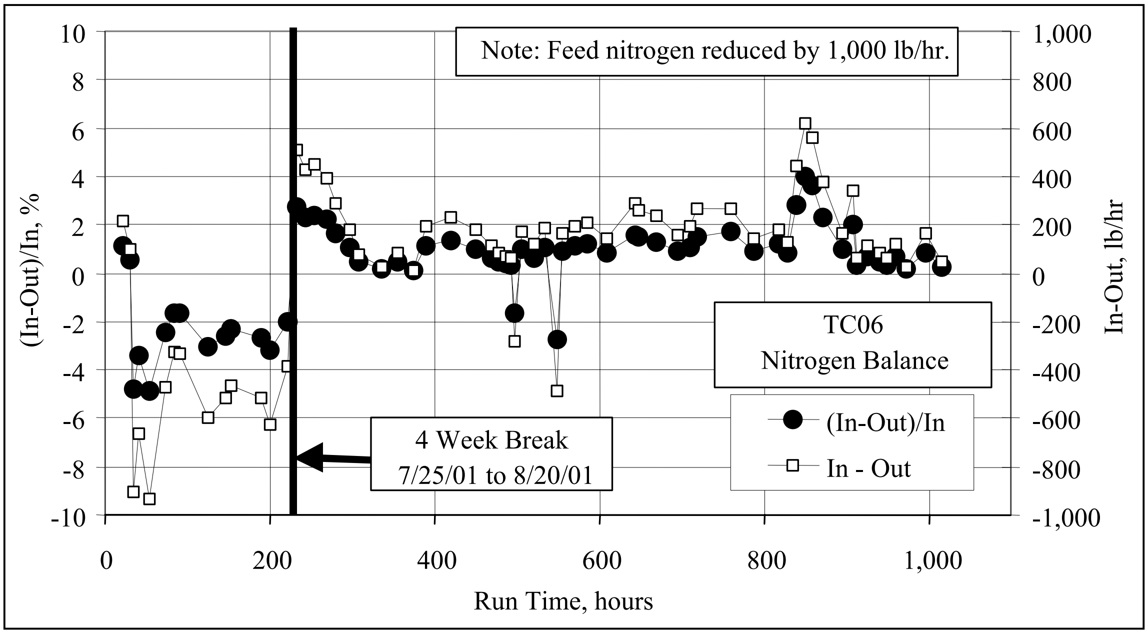

Figure 4.5-8 Nitrogen Balance

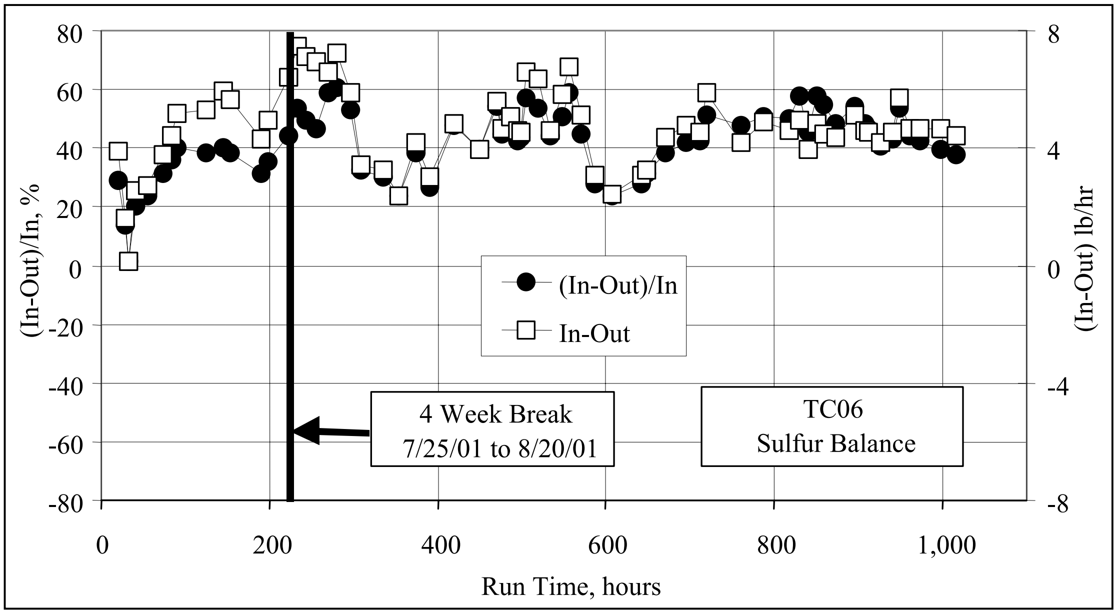

Figure 4.5-9 Sulfur Balance

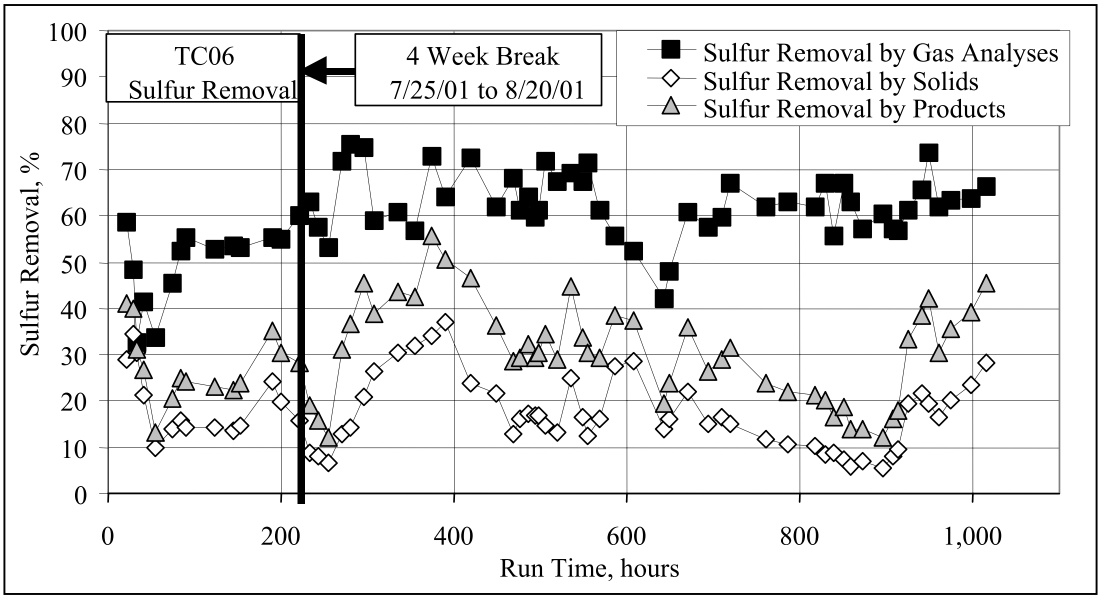

Figure 4.5-10 Sulfur Removal

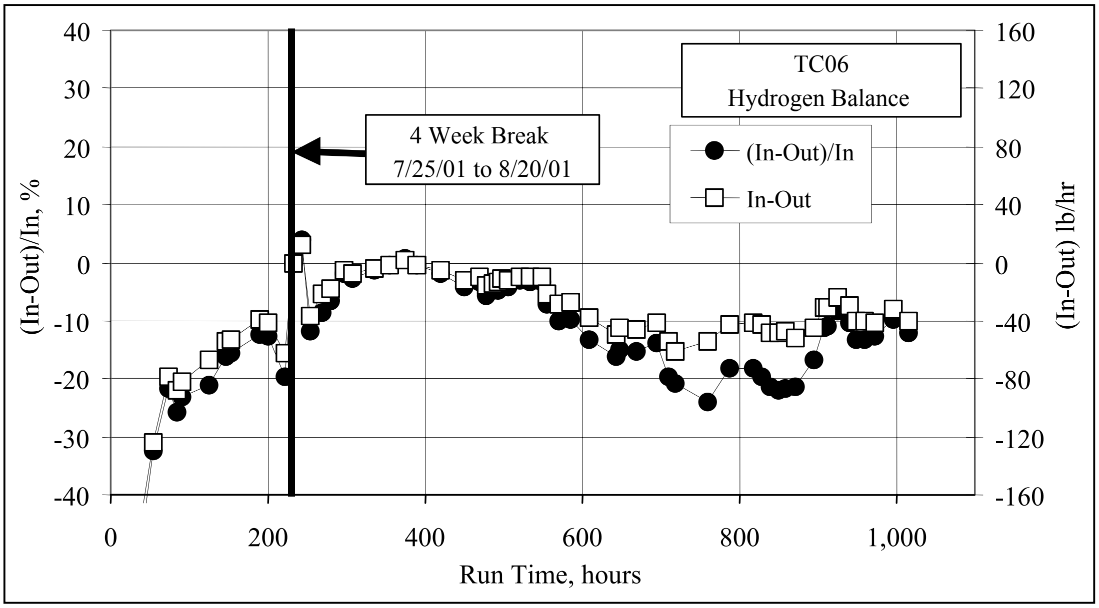

Figure 4.5-11 Hydrogen Balance

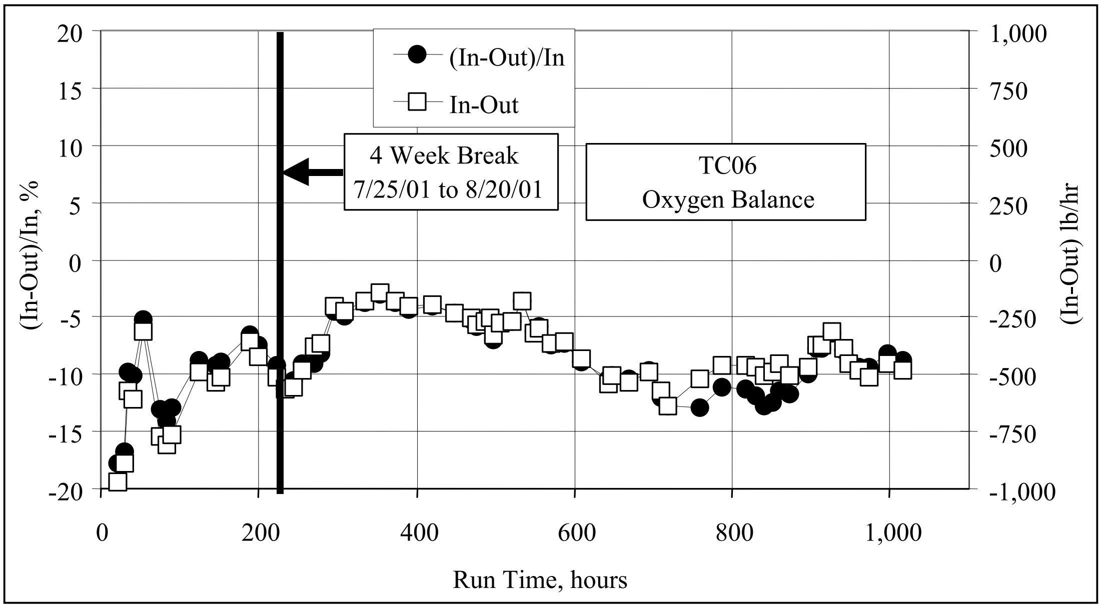

Figure 4.5-12 Oxygen Balance

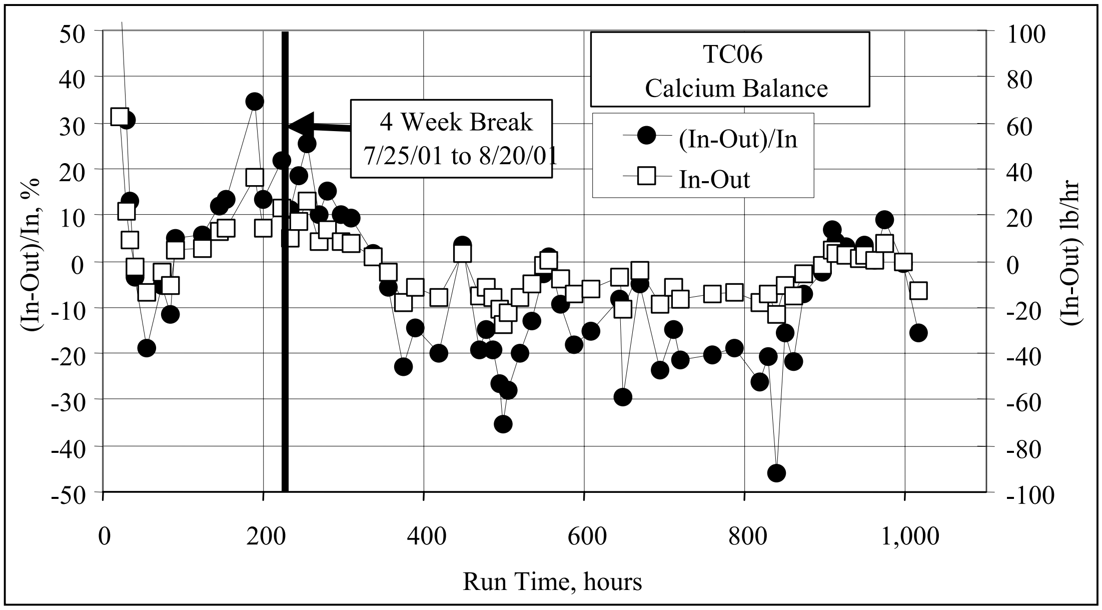

Figure 4.5-13 Calcium Balance

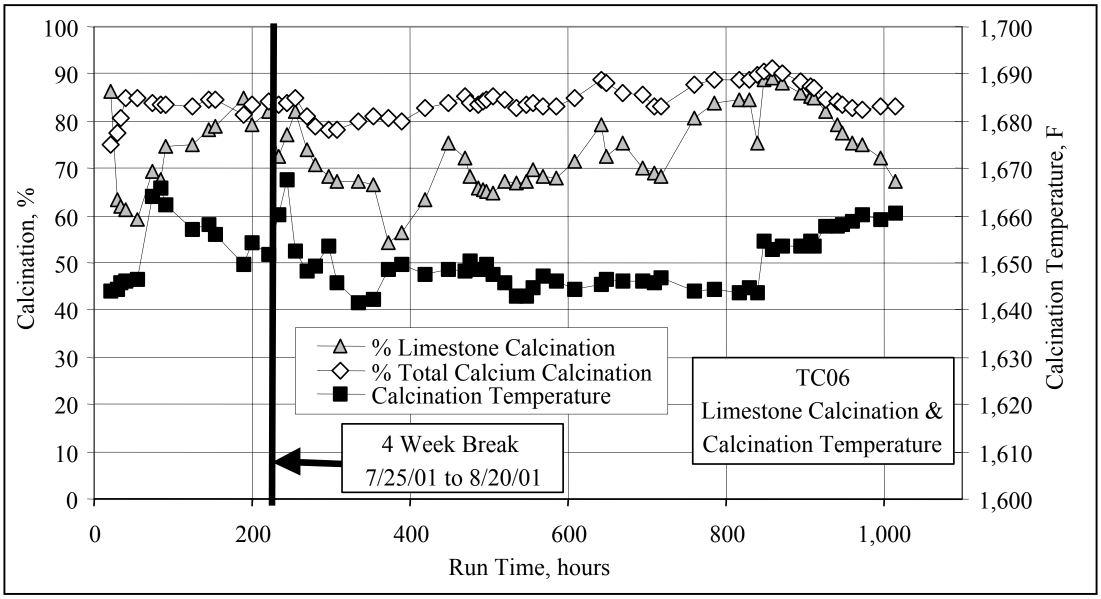

Figure 4.5-14 Calcination and Calcination Temperature

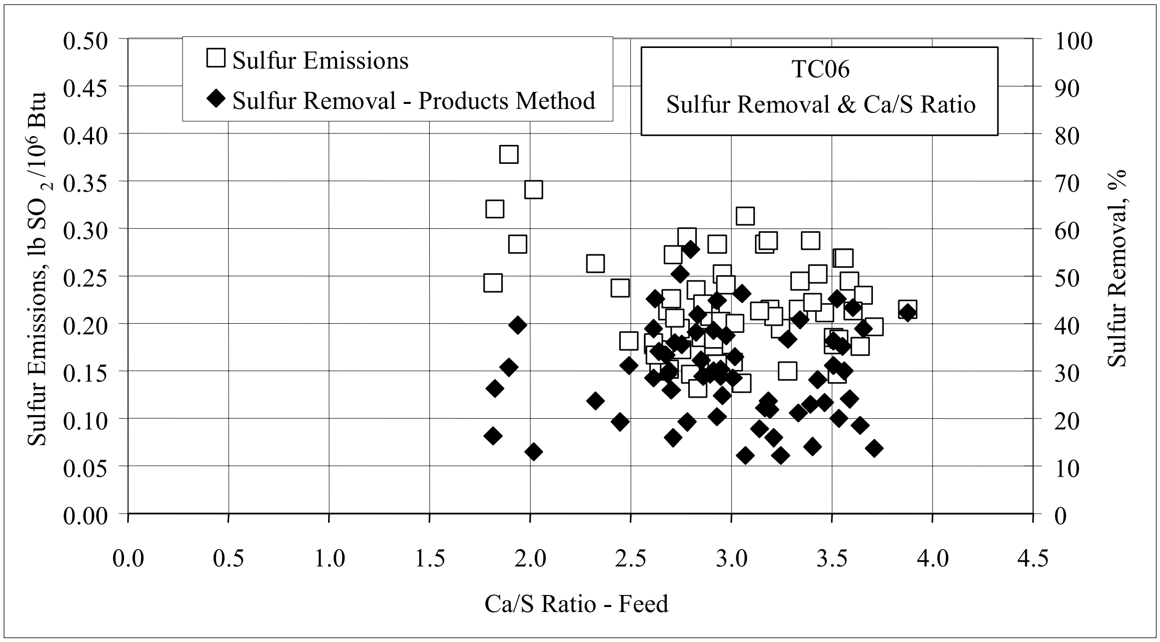

Figure 4.5-15 Sulfur Emissions and Feed Ca/S Ratio

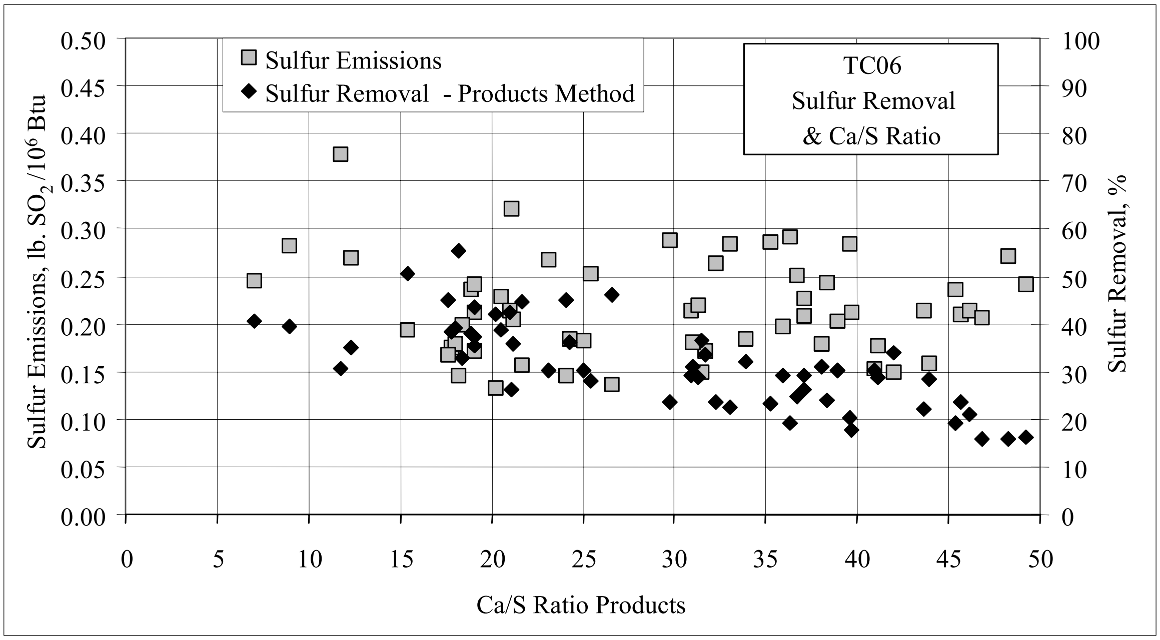

Figure 4.5-16 Sulfur Emissions and PCD Solids Ca/S Ratio

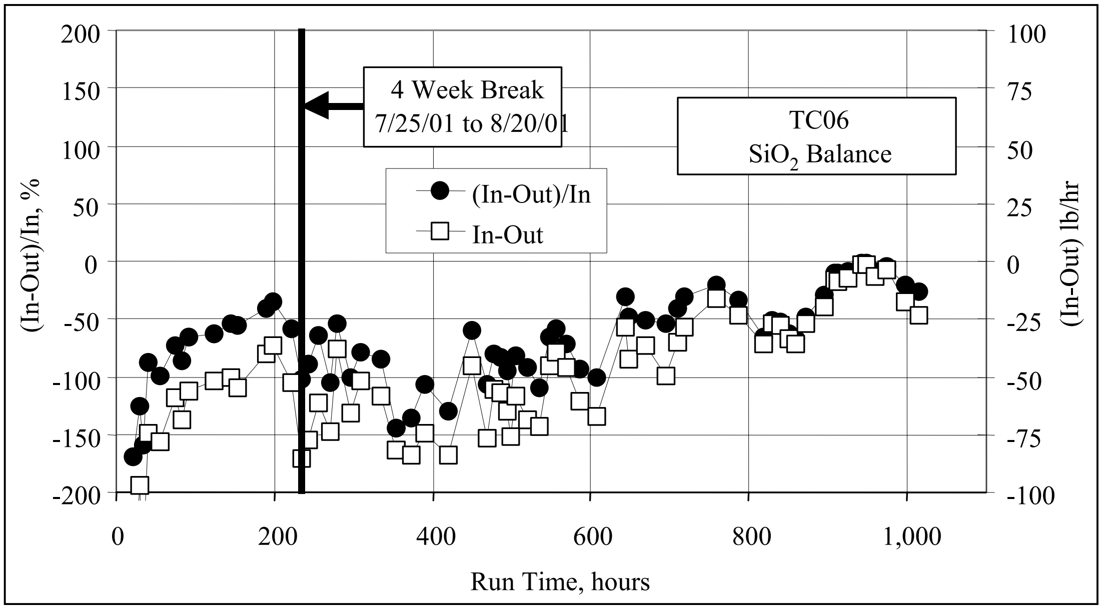

Figure 4.5-17 SiO2 Balance

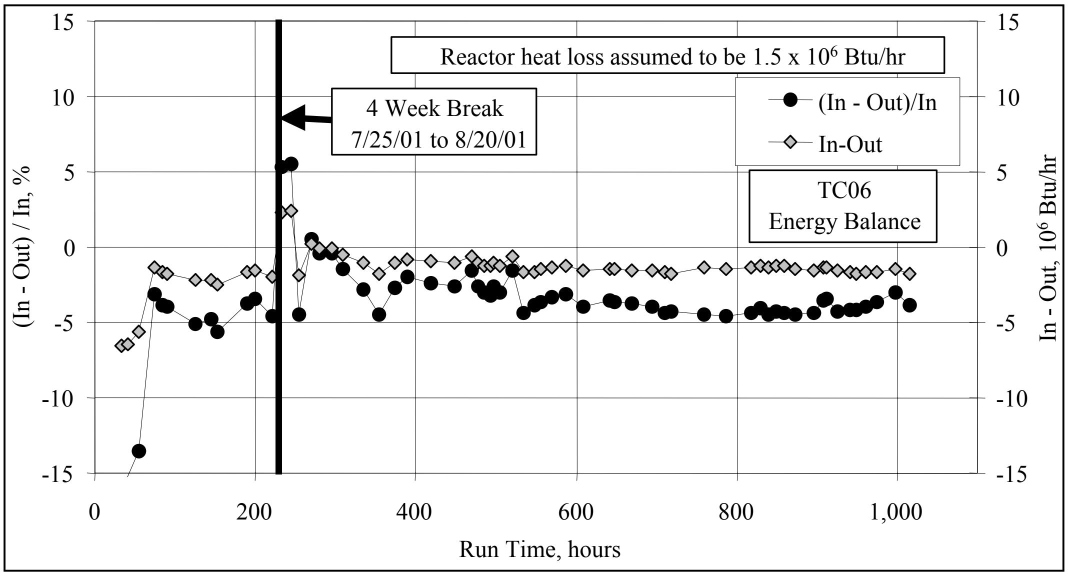

Figure 4.5-18 Energy Balance

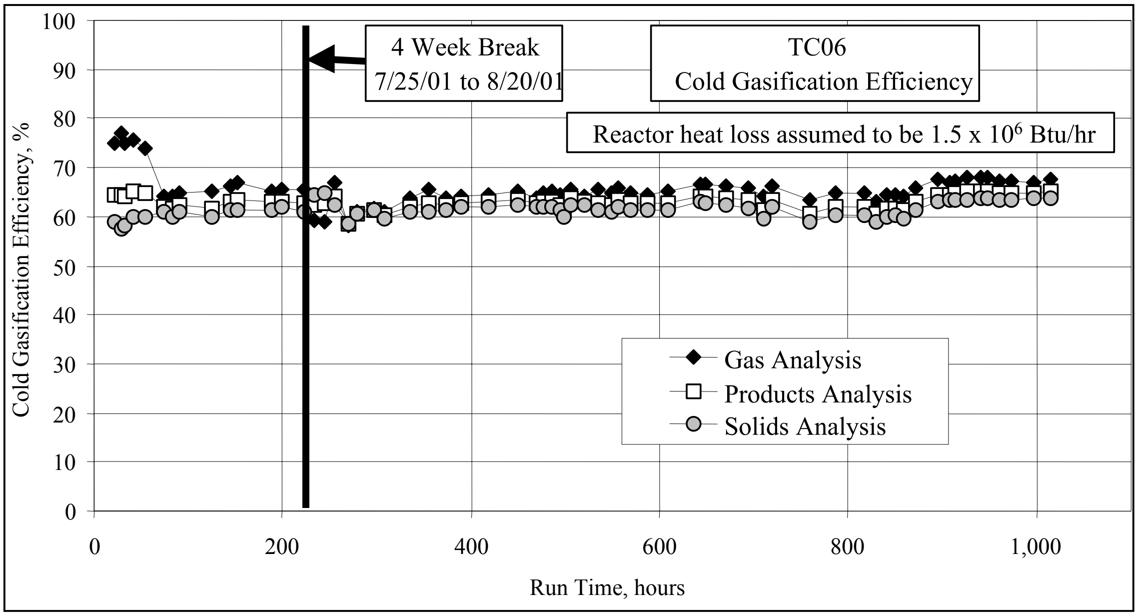

Figure 4.5-19 Cold Gasification Efficiency

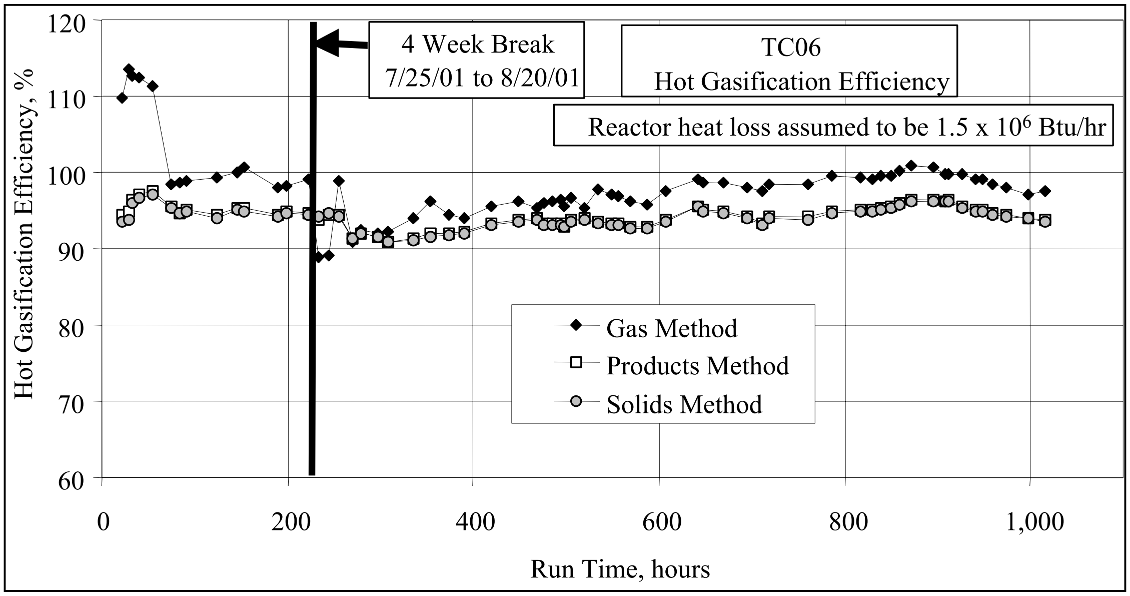

Figure 4.5-20 Hot Gasification Efficiency

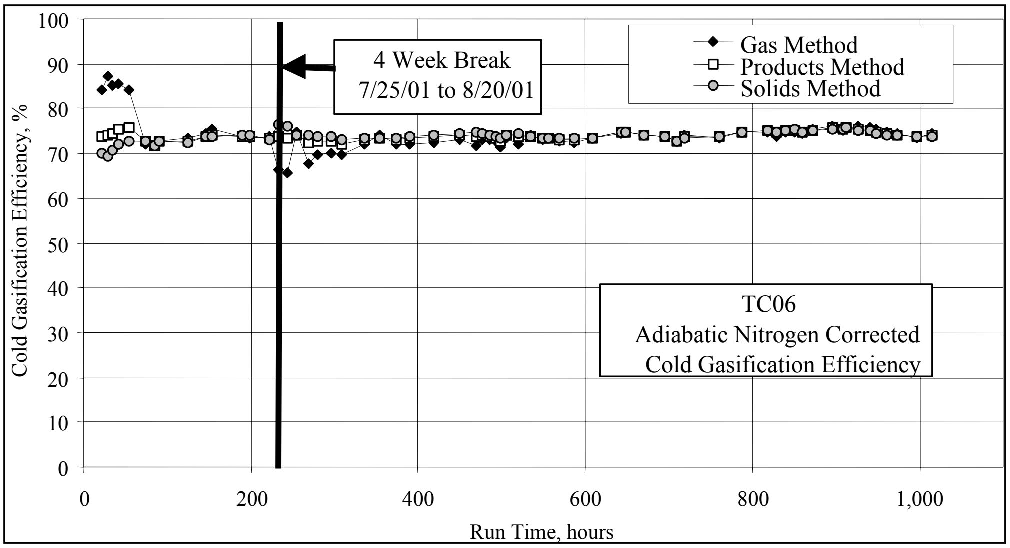

Figure 4.5-21 Nitrogen-Corrected Cold Gasification Efficiency

4.6 SULFATOR OPERATIONS

During TC06, the sulfator (atmospheric fluidized-bed combustor, AFBC) was operated for almost 1,500 hours and fired gasification ash (g-ash) from the gasifier for a total of 524 hours. The average bed temperature during fuel feed was about 1,370ºF with about 12 percent of the time spent above 1,500ºF compared to a design operating temperature of 1,600 to 1,650ºF. The lower temperature operations were sufficient to achieve high carbon conversion and to sulfate calcium sulfide to calcium sulfate. Figure 4.6-1 shows the percentage of carbon found in the g-ash fed to the sulfator and in the ash exiting the sulfator. The carbon content in the feed material to sulfator ranged from 10 to 50 percent. A large percentage of feed to the sulfator was fine ash, sorbent-derived materials and g-ash collected by PCD. The carbon content of the fine ash from the sulfator was below 1 percent. Figure 4.6-2 shows the percentage sulfides found in the g-ash fed to the sulfator and in the ash exiting the sulfator. The sulfides in PCD fines ranged from 0.2 to 1.5 percent, while the sulfide content of fine ash from sulfator was nearly zero during most of the test run, indicating high conversion of sulfide to sulfate in the sulfator.

At startup, the sulfator is filled with sand as a start-up bed material. As the run progresses, some of the same are elutriated out of the bed while some of the ash material from the g-ash collects in the bed. Most of the g-ash fed to the sulfator is fine and it is carried over to the baghouse with little accumulation in the sulfator. Figure 4.6-3 shows the average particle size of the g-ash feed, the ash carried over to the baghouse, and the solids collected from the sulfator overflow. Notice that the feed has a very small particle size and that the average particle size of the bed declines as ash accumulates, which is due to attrition and elutriation of the sand.

During previous runs the bed has become less well mixed as the test run progressed. Early in the run all bed thermocouples will read within about 100ºF of one another, but after a few hundred hours of operation the range can be greater than 1,000ºF. This has been attributed to refractory that has spalled from the walls blocking some of the nozzles on the air distribution grid. Before TC06, the refractory walls of the sulfator were sprayed with sodium silicate to harden the refractory. As can be seen in Figure 4.6-4, the temperature profile remained within a narrow range throughout TC06. In addition, an inspection carried out after the run indicated that the refractory was mostly intact.

To help with startup, a modification was made to the sulfator steam system prior to TC06. The steam flow control valve is unable to adequately control steam flow at the lower flows that is needed for startup. This results in much higher than needed steam flow to the cooling coils and reduced bed temperature. To counter this, a small bypass has been added around the main control valve with a smaller controller to be used for start-up conditions. For TC06, this arrangement provided about 40ºF higher bed temperature from the start-up heater. Additional gains in bed temperature from the heater are expected to be achieved in future test runs as the new configuration can further reduce steam flow.

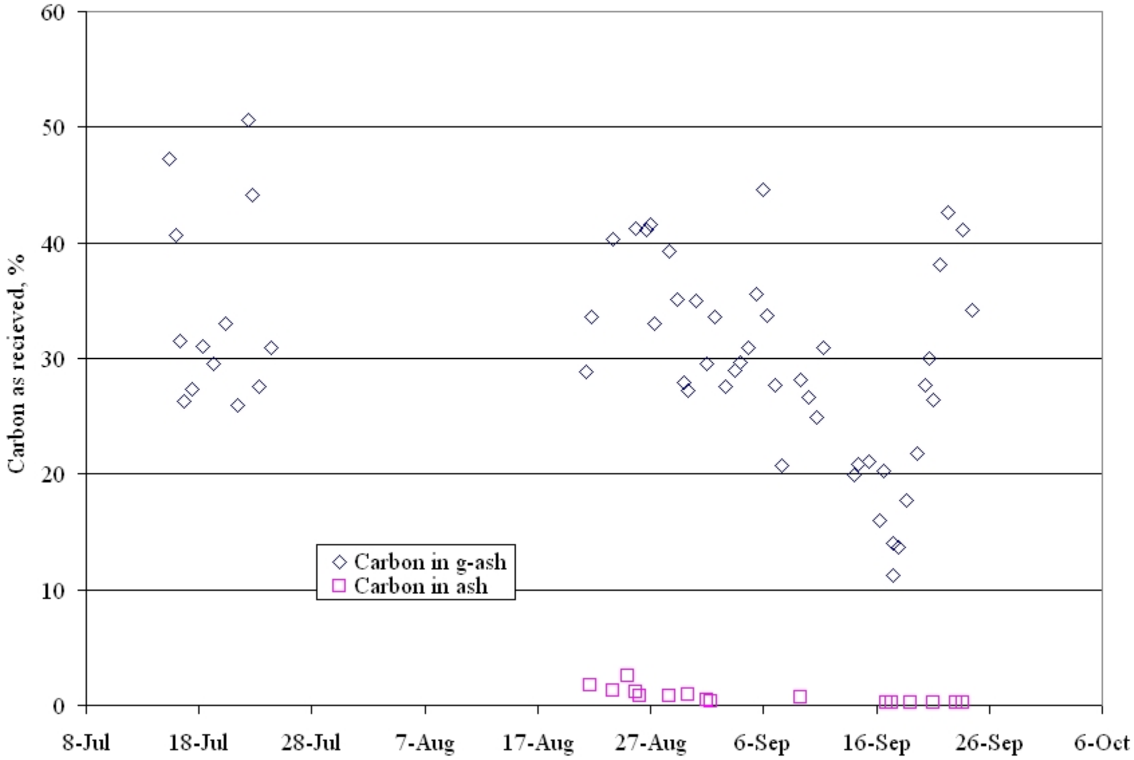

Figure 4.6-1 Carbon in G-ash (Feed) and Ash

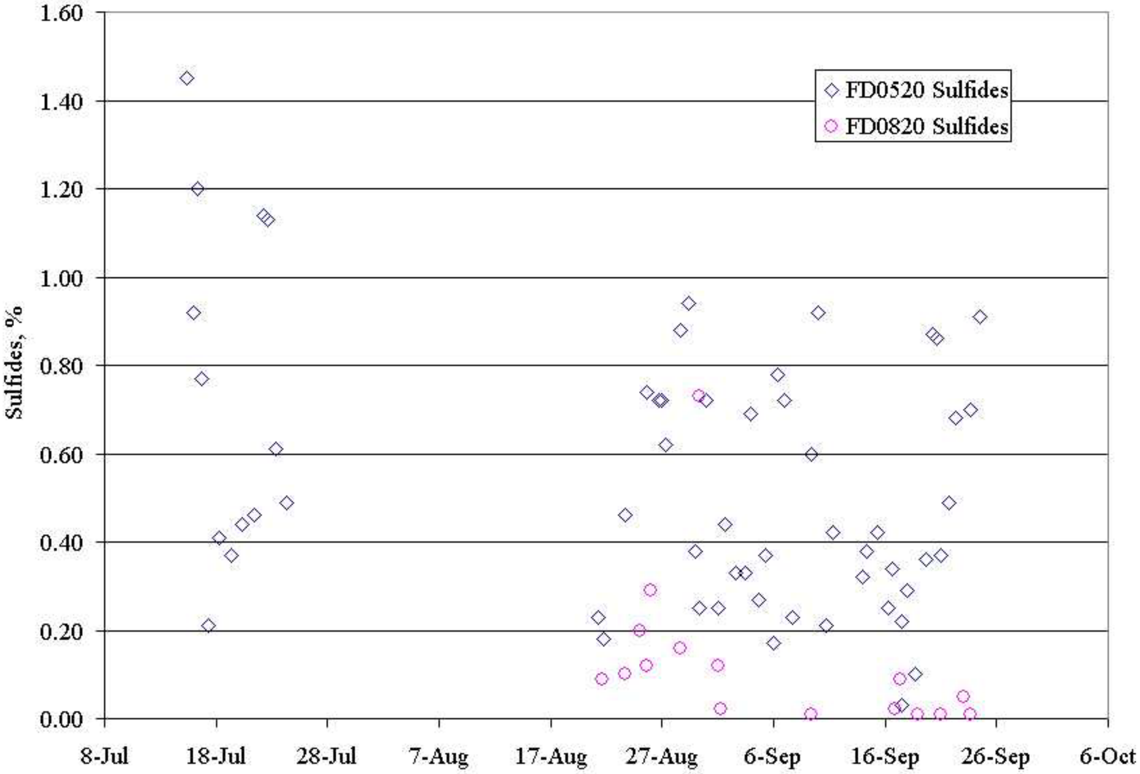

Figure 4.6-2 Sulfides in G-ash (Feed) and Ash

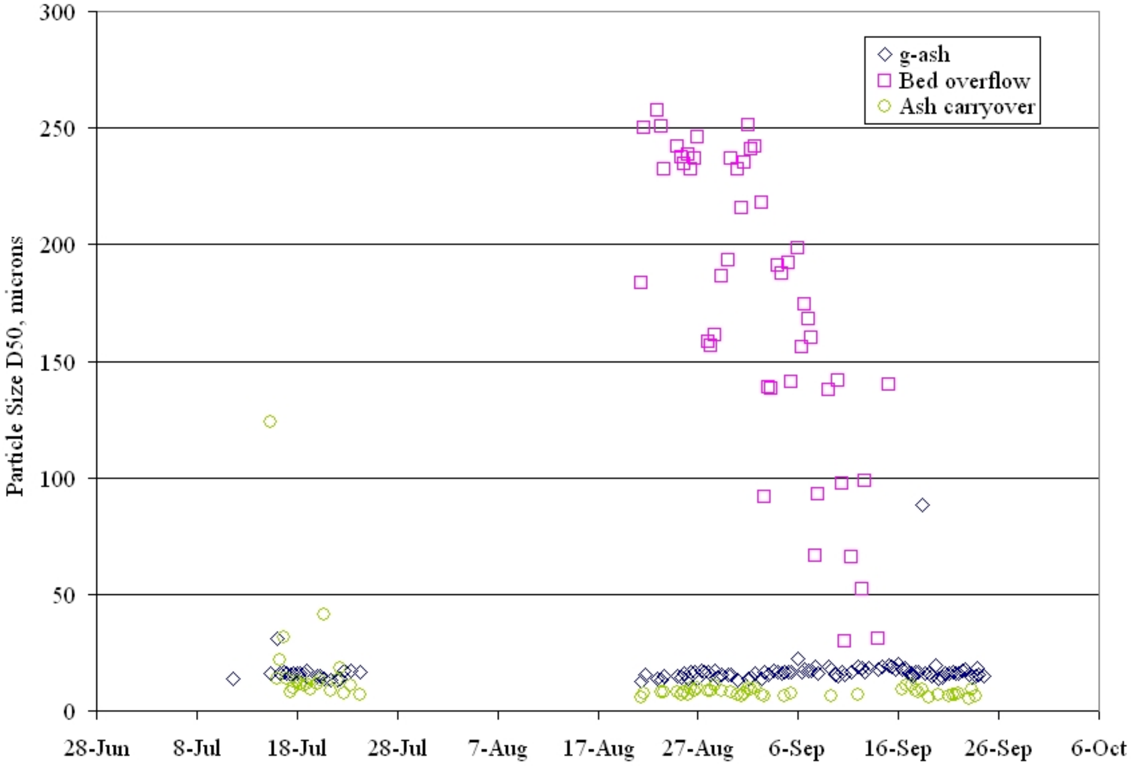

Figure 4.6-3 Particle Size of Feed G-ash, Ash, and Bed

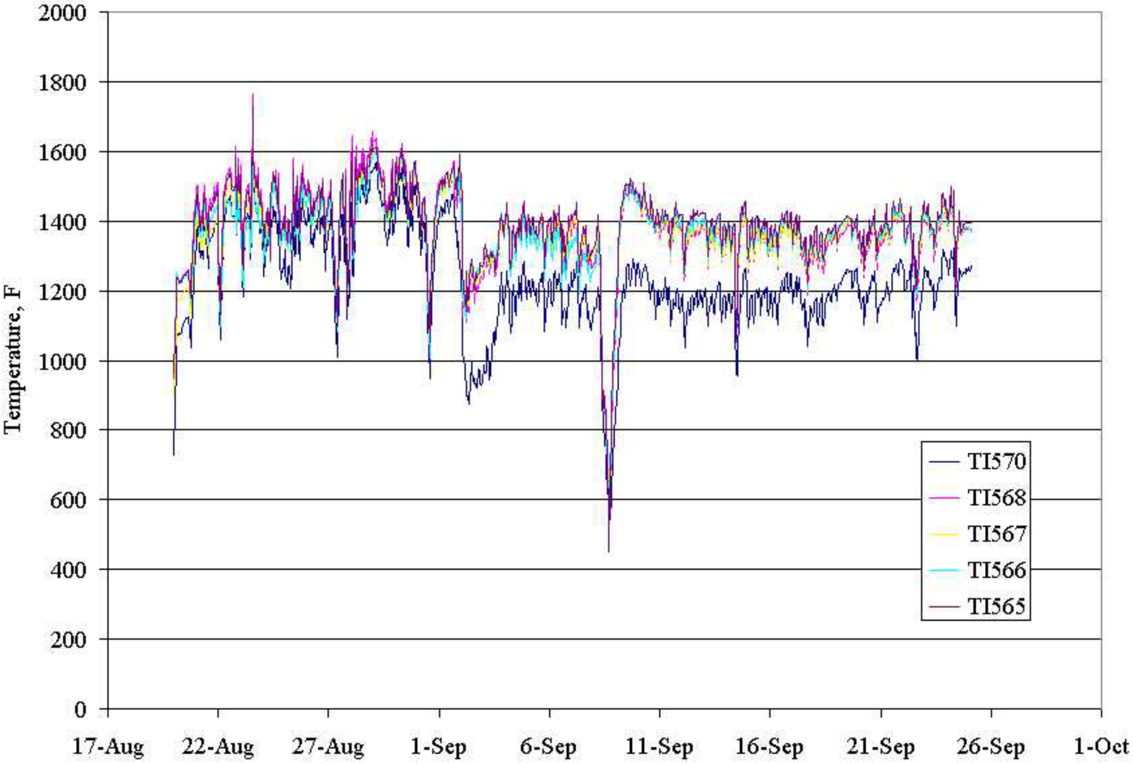

Figure 4.6-4 Temperature Profile of Bed

4.7 PROCESS GAS COOLERS

Heat transfer calculations were done on the primary gas cooler, HX0202, and the secondary gas cooler, HX0402, to determine if their performance had deteriorated during TC06 due to tar or other compounds depositing on the tubes.

The primary gas cooler is between the Transport Reactor cyclone, CY0201, and the Siemens Westinghouse PCD, FL0301. During TC06, HX0202 was not bypassed and took the full gas flow from the Transport Reactor. The primary gas cooler is single-flow heat exchanger with hot gas from the Transport Reactor flowing through the tubes and the shell side operating with the plant steam system. The pertinent equations are:

$$Q = UA\Delta T_{LM} \tag{1}$$

$$Q = c_p M(T_1 - T_2) \tag{2}$$

$$\Delta T_{LM} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \dfrac{(T_1 - t_2)}{(T_2 - t_1)}} \tag{3}$$

Q = Heat transferred, Btu/hour
U = Heat transfer coefficient, Btu/hr/ft^2/°F
A = Heat exchanger area, ft^2
ΔT_{LM} = Log mean temperature difference, °F
c_p = Gas heat capacity, Btu/lb/°F
M = Mass flow of gas through heat exchanger, lb/hr
T_1 = Gas inlet temperature, °F
T_2 = Gas outlet temperature, °F
t_1 = t_2 = Steam temperature, °F

Using Equations (1) through (3) and the process data, the product of the heat transfer coefficient and the heat exchanger area (UA) can be calculated. The TC06 HX0202 UA is shown on Figure 4.7-1 as 4-hour averages, along with the design UA of 5,200 Btu/hr/°F and the pressure drop across HX0202. If HX0202 is plugging, the UA should decrease and the pressure drop should increase. The UA deterioration is a better indication of heat exchanger plugging because the pressure drop is calculated by the difference of two numbers of about the same size, usually from 150 to 240 psig, resulting in pressure drops of 1 to 3 psi.

The TC06 UA rose up to about 10,500 Btu/hr/°F after about 50 hours of operation, well above the design UA of 5,200 Btu/hr/°F. The UA of about 10,500 Btu/hr/°F was maintained until just after the 4-week break. After the 4-week break the UA slowly rose from 8,500 to 10,300 Btu/hr/°F. There were several periods when the UA rose to above 12,000 Btu/hr/°F (hours

635 to 671, 759, 839, and 883 to 907). These were periods when the HX0202 outlet temperature thermocouple TI440 was malfunctioning. Periods of low UA were during coal trips.

The HX0202 pressure drop trends paralleled those of UA. The pressure drop rose to between 2.0 and 2.5 during the first 50 hours of TC06, then slowly decreased to between 1.6 and 2.2 psi. After the 4-week break, the pressure drop slowly increased from about 1.4 psi to about 2.0 psi at hour 895. The pressure drop then increased to between 2.7 and 3.5 during the high coal-rate operation. There appeared to be no plugging during TC06. This analysis fails to notice the HX0202 steam leak that was discovered after the completion of TC06.

The GCT4 test run had HX0202 UAs at 7,000 to 8,000 Btu/hr/°F (lower than TC06) which were in the range of 9,000 to 10,500 Btu/hr/°F. The pressure drops for GCT4 HX0402 (1.0 to 2.0 psi) were lower than TC06 pressure drops (1.4 to 3.0 psi).

The secondary gas cooler, HX0402, is single-flow heat exchanger with hot gas from the PCD flowing through the tubes and the shell side operating with plant steam system. Some heat transfer and pressure drop calculations were done around HX0402 to determine if there was any plugging or heat exchanger performance deterioration during TC06. HX0402 is not part of the combustion gas turbine commercial flow sheet. In the commercial gas turbine flow sheet, the hot synthesis gas from the PCD would be directly sent to a combustion gas turbine. HX0402 would be used commercially if the synthesis gas was to be used in a fuel cell or as a chemical plant feedstock.

Using Equations (1) through (3) and the process data, the product of the heat transfer coefficient and the heat exchanger area (UA) can be calculated. The UA for TC06 testing is shown in Figure 4.7-2 as 4-hour averages, along with the design UA of 13,100 Btu/hr/°F and the pressure drop across HX0402. If HX0402 is plugging, the UA should decrease and the pressure drop should increase.

The UA was at 17,000 to 18,000 Btu/hr/°F for the first 255 hours of TC06, well above the design UA of 13,100 Btu/hr/°F. After hour 255, the UA was very constant at 16,000 Btu/hr/°F until hour 719, when the coal-feed rate was reduced. The UA decreased to 14,800 Btu/hr/°F until the coal rate was increased at hour at 895. The UA then increased to 16,600 Btu/hr/°F by the end of TC06.

The HX0402 TC06 pressure drop was between at 3.5 and 4.5 psi for the first 255 hours of TC06 operation. After hour 255, the pressure drop decreased to about 3.0 psi. The pressure drop then slowly increased up to 3.8 psi at hour 623. When the coal rate was decreased the pressure drop decreased to 2.5 psi until the coal rate was increased at hour 895. The pressure dropped then increased to 3.5 at the end of TC06. There was no evidence of HX0402 plugging during the first 5 days of operation.

The GCT4 test run had HX0402 UAs at 14,000 to 17,000, which were in the same range as TC06 at 14,500 to 18,000 Btu/hr/°F. The pressure drops for GCT4 HX0402 (1.5 to 3.5 psi) were slightly less than TC06 (2.0 to 4.5 psi).

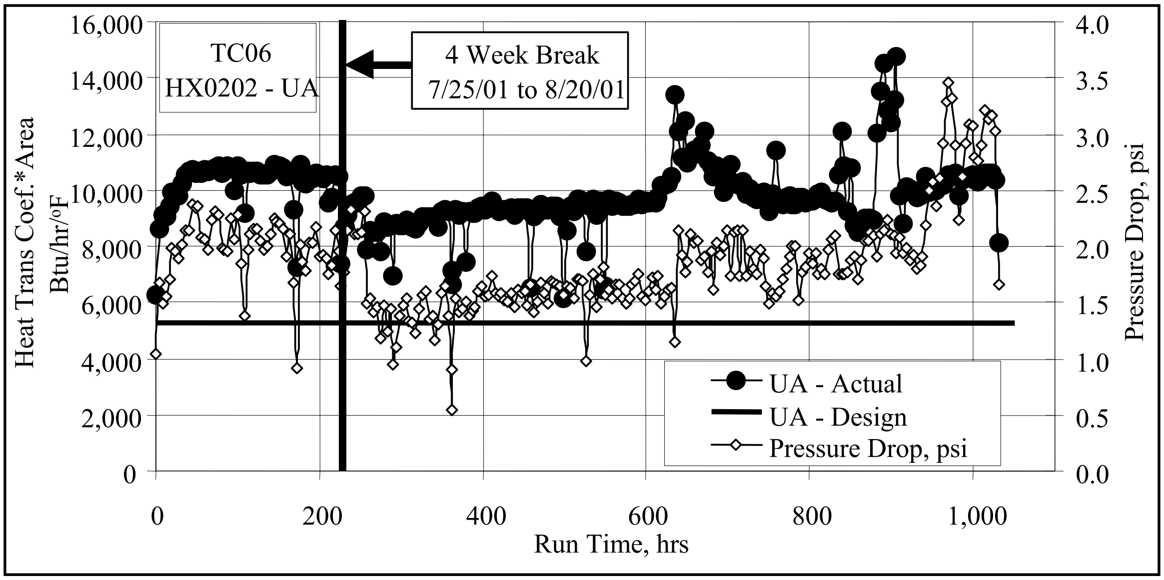

Figure 4.7-1 HX0202 Heat Transfer Coefficient and Pressure Drop

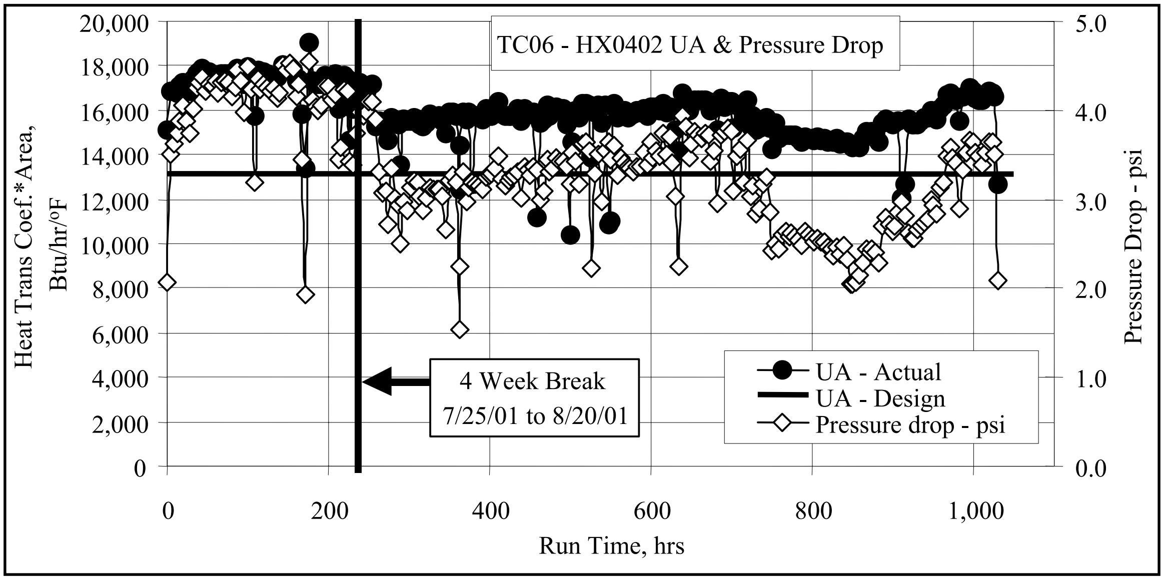

Figure 4.7-2 HX0402 Heat Transfer Coefficient and Pressure Drop

TERMS

Listing of Abbreviations

AAS	Automated Analytical Solutions
ADEM	Alabama Department of Environmental Management
AFBC	Atmospheric Fluidized-Bed Combustor
APC	Alabama Power Company
APFBC	Advance Pressurized Fluidized-Bed Combustion
ASME	American Society of Mechanical Engineers
AW	Application Workstation
BET	Brunauer-Emmett-Teller (nitrogen-adsorption specific surface technique)
BFI	Browning-Ferris Industries
BFW	Boiler Feed Water
BMS	Burner Management System
BOC	BOC Gases
BOP	Balance-of-Plant
BPIR	Ball Pass Inner Race, Frequencies
BPOR	Ball Pass Outer Race, Frequencies
BSF	Ball Spin Frequency
CAD	Computer-Aided Design
CAPTOR	Compressed Ash Permeability Tester
CEM	Continuous Emissions Monitor
CFB	Circulating Fluidized Bed
CFR	Code of Federal Regulations
CHE	Combustor Heat Exchanger
COV	Coefficient of Variation (Standard Deviation/Average)
CPC	Combustion Power Company
CPR	Cardiopulmonary Resuscitation
CTE	Coefficient of Thermal Expansion
DC	Direct Current
DCS	Distributed Control System
DHL	DHL Analytical Laboratory, Inc.
DOE	U.S. Department of Energy
DSRP	Direct Sulfur Recovery Process
E & I	Electrical and Instrumentation
EERC	Energy and Environmental Research Center
EPRI	Electric Power Research Institute
EDS or EDX	Energy-Dispersive X-Ray Spectroscopy
ESCA	Electron Spectroscopy for Chemical Analysis
FCC	Fluidized Catalytic Cracker
FCP	Flow-Compacted Porosity
FFG	Flame Front Generator
FI	Flow Indicator
FIC	Flow Indicator Controller
FOAK	First-of-a-Kind
FTF	Fundamental Train Frequency

FW	Foster Wheeler
GBF	Granular Bed Filter
GC	Gas Chromatograph
GEESI	General Electric Environmental Services, Inc.
HHV	Higher Heating Valve
HP	High Pressure
HRSG	Heat Recovery Steam Generator
HTF	Heat Transfer Fluid
HTHP	High-Temperature, High-Pressure
I/O	Inputs/Outputs
ID	Inside Diameter
IF&P	Industrial Filter & Pump
IGV	Inlet Guide Vanes
IR	Infrared
KBR	Kellogg Brown & Root, Inc.
LAN	Local Area Network
LHV	Lower Heating Valve
LIMS	Laboratory Information Management System
LMZ	Lower Mixing Zone
LOC	Limiting Oxygen Concentration
LOI	Loss on Ignition
LPG	Liquefied Propane Gas
LSLL	Level Switch, Low Level
MAC	Main Air Compressor
MCC	Motor Control Center
MMD	Mass Median Diameter
MS	Microsoft Corporation
NDIR	Nondestructive Infrared
NETL	National Energy Technology Laboratory
NFPA	National Fire Protection Association
NO_x	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NPS	Nominal Pipe Size
OD	Outside Diameter
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OSI	OSI Software, Inc.
P&IDs	Piping and Instrumentation Diagrams
PC	Pulverized Coal
PCD	Particulate Control Device
PCME	Pollution Control & Measurement (Europe)
PDI	Pressure Differential Indicator
PDT	Pressure Differential Transmitter
PFBC	Pressurized Fluidized-Bed Combustion
PI	Plant Information
PLC	Programmable Logic Controller
PPE	Personal Protection Equipment

PRB	Powder River Basin
PSD	Particle-Size Distribution
PSDF	Power Systems Development Facility
ΔP or DP or dP	Pressure Drop or Differential Pressure
PT	Pressure Transmitter
RAPTOR	Resuspended Ash Permeability Tester
RFQ	Request for Quotation
RO	Restriction Orifice
RPM	Revolutions Per Minute
RSSE	Reactor Solid Separation Efficiency
RT	Room Temperature
RTI	Research Triangle Institute
SCS	Southern Company Services, Inc.
SEM	Scanning Electron Microscopy
SGC	Synthesis Gas Combustor
SMD	Sauter Mean Diameter
SRI	Southern Research Institute
SUB	Start-up Burner
TCLP	Toxicity Characteristic Leaching Procedure
TR	Transport Reactor
TRDU	Transport Reactor Demonstration Unit
TRS	Total Reduced Sulfur
TSS	Total Suspended Solids
UBP	Uncompacted Bulk Porosity
UMZ	Upper Mixing Zone
UND	University of North Dakota
UPS	Uninterruptible Power Supply
UV	Ultraviolet
VFD	Variable Frequency Drive
VOCs	Volatile Organic Compounds
WGS	Water-Gas Shift
WPC	William's Patent Crusher
XRD	X-Ray Diffraction
XXS	Extra, Extra Strong

Listing of Units

acfm	actual cubic feet per minute
Btu	British thermal units
°C	degrees Celsius or centigrade
°F	degrees Fahrenheit
ft	feet
FPS	feet per second
gpm	gallons per minute
g/cm^3 or g/cc	grams per cubic centimeter
g	grams
GPa	gigapascals
hp	horsepower
hr	hour
in.	inches
inWg (or inWc)	inches, water gauge (inches, water column)
in.-lb	inch pounds
°K	degrees Kelvin
kg	kilograms
kJ	kilojoules
kPa	kilopascals
ksi	thousand pounds per square inch
m	meters
MB	megabytes
min	minute
mm	millimeters
MPa	megapascals
msi	million pounds per square inch
MW	megawatts
m/s	meters per second
MBtu	Million British thermal units
m^2/g	square meters per gram
μ or μm	microns or micrometers
dp_{50}	particle-size distribution at 50 percentile
ppm	parts per million
ppm (v)	parts per million (volume)
ppm (w)	parts per million (weight)
lb	pounds
pph	pounds per hour
psi	pounds per square inch
psia	pounds per square inch absolute
psid	pounds per square inch differential
psig	pounds per square inch gauge
ΔP	pressure drop
rpm	revolutions per minute
s or sec	seconds
scf	standard cubic feet

scfh	standard cubic feet per hour
scfm	standard cubic feet per minute
V	volts
W	watts