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Technical Paper "Microfine Coal Firing Results from a Retrofit Gas/Oil-Designed Industrial Boiler"

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MICROFINE COAL FIRING RESULTS FROM A RETROFIT GAS/OIL-DESIGNED INDUSTRIAL BOILER

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INTRODUCTION/ BACKGROUND

Under U.S. Department of Energy, Pittsburgh Energy Technology Center (PETC) support, the development of a High Efficiency Advanced Coal Combustor (HEACC) has been in progress since 1987 at the ABB Power Plant Laboratories (Rini, et al., 1987, 1988). The initial work on this concept produced an advanced coal firing system that was capable of firing both water-based and dry pulverized coal in an industrial boiler environment (Rini, et al., 1990).

Economics may one day dictate that it makes sense to replace oil or natural gas with coal in boilers that were originally designed to burn these fuels. In recognition of this future possibility, the U.S. Department of Energy, Pittsburgh Energy Technology Center (PETC) has continued to support this program led by ABB Power Plant Laboratories and the Fuels Research Center of Penn State University to develop the HEACC concept. The objective of the current program is to demonstrate the technical and economic feasibility of retrofitting a gas/oil designed boiler to burn micronized coal. In support of this overall objective, the following specific areas were targeted:

- A coal handling/preparation system that can meet the technical requirements for retrofitting microfine coal on a boiler designed for burning oil or natural gas.
- Maintaining boiler thermal performance in accordance with specifications when burning oil or natural gas.
- Maintaining NOx emissions at or below 0.6 lb/MBtu (~450 ppm)
- Achieving combustion efficiencies of 98% or higher
- Calculating economic payback periods as a function of key variables

The overall program has consisted of five major tasks:

1.0 A review of current state-of-the-art coal firing system components.
2.0 Design and experimental testing of a prototype HEACC burner.
3.0 Installation and testing of a HEACC system in a commercial retrofit application.
4.0 Economic evaluation of the HEACC concept for retrofit applications.
5.0 Long term demonstration under commercial user demand conditions

This paper will summarize the latest key experimental results (Task 3) and the economic evaluation (Task 4) of the HEACC concept for retrofit applications.

BURNER INSTALLATION AND TESTING IN AN INDUSTRIAL BOILER

The overall objective of this program has been to assess the technical and economic viability of displacing premium fuels with micro-fine coal by retrofitting the previously developed High Efficiency Advanced Coal Combustor (HEACC) to a gas/oil designed industrial boiler. This paper summarizes the work involving the retrofit of a complete micro-fine pulverized coal milling and firing system to an existing 15,000 lb/hr package boiler located in the East Steam Plant of Penn State University. Combustion performance-related objectives included steady state operation on 100% coal while achieving a carbon conversion efficiency of 98%, without increasing NOx emissions above 0.6 lb/MBtu (~450 ppm). The testing was also designed to show that consistent, reliable operation of entire coal storage/handling and pulverization system could be achieved. Reliable operation of the coal preparation system in concert with satisfactory burner performance would serve as a prerequisite to the demonstration phase of the project.

The HEACC burner was previously tested (Task 2) in the Industrial Scale Burner Facility (ISBF) located at Combustion Engineering's ABB Power Plant Laboratories (PPL) in Windsor, Connecticut. A key objective of the 100 hour burner validation tests at PPL was to fine-tune the burner operating characteristics and demonstrate operation over the range of conditions expected for the field boiler tests. All performance goals were successfully achieved during these ISBF tests. The testing at PPL demonstrated the technical validity of the design improvements incorporated into the second generation HEACC. This burner was then installed as part of a complete coal handling and firing system in Penn State's commercial boiler for a 400 hour proof-of-concept test program (Task 3).

A schematic of the micronized coal preparation/firing system at Penn State is shown in Figure 1. As can be seen, the cleaned coal comes on site and is stored in a large hopper. The coal is crushed and sent via a screw feeder to a micronized coal mill (TCS system). The coal is then micronized to ~80% through 325 mesh (~18 microns MMD) in the TCS mill and pneumatically conveyed to the HEACC burner where it is then burned in the boiler. This boiler is an oil/gas designed Tampella Keeler Model DS-15; a package D-type watertube boiler capable of producing 15,000 lb/hr of saturated steam at 300 psig. It represents a typical gas/oil - designed system with a furnace volumetric heat release of 50,000 Btu/hr ft^3, standard for this class of boiler. Furthermore, its design is similar to that of many other manufacturers' (including Combustion Engineering) models.

EXPERIMENTAL TESTING RESULTS

A) OVERVIEW

During the long term test period, the boiler system was operated over a range of operating conditions. Specifically, the boiler was tested over a variety of load ranges, excess air, combustion air damper settings and burner swirl levels. Two coals Brookville Seam and Kentucky were used. Their analyses are summarized in Table 1. During the test period, boiler performance data, emissions data, electric parasitic power and house compressed air consumption data, as well as other data required for the technical and economical analysis of the system were obtained.

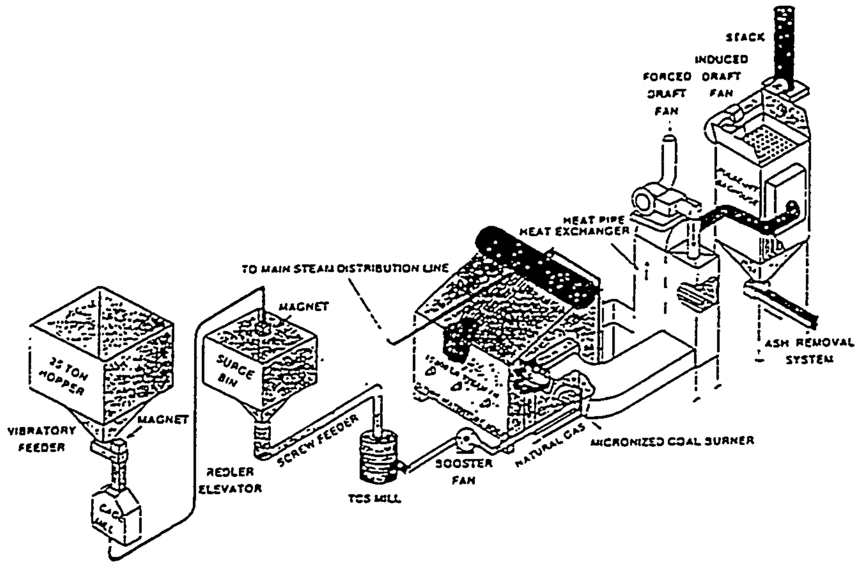

Figure 1 Micronized Coal Combustion System at Penn State

The initial burner tests included a shakedown series of runs using natural gas firing (Jennings, et al., 1994a, 1994b). At the conclusion of baseline natural gas firing, the boiler operation was directed towards hardware optimization (e.g., coal handling/preparation, burner settings) and testing with 100% coal firing. During this phase of the work, a major objective was to obtain consistent, repeatable 100% coal fired runs. This goal, along with minor modifications to the system (discussed in the next section) to increase boiler and carbon conversion efficiency resulted in several short term tests. Subsequently, the chosen hardware configuration was then used during the long term (~400 hr) test program (Task 3).

Table 1 Selected Analyses of the Brookville and Kentucky Coals

	Brookville Seam	Kentucky
Proximate, wt%		
Moisture	8.2	6.8
Volatile Matter	33.1	33.3
Fixed Carbon	55.8	55.4
Ash	2.9	4.5
HHV, Btu/lb	13,260	13,010
Ash Fusion Temp, °F		
IDT	2,820	2,803
ST	+3,000	+3,000
FT	+3,000	+3,000

B) SYSTEM CHARACTERIZATION/MODIFICATIONS

A key objective of the proof of concept testing was to determine the operating characteristics of the complete, integrated system in contrast to the operation of the individual components. Although all of the system components installed at the demonstration boiler host site were proven in either commercial operation or prior testing, the complete system from micro-fine coal production to steam production at this scale had not been previously demonstrated/proven.

The testing at Penn State indicated areas that should be carefully engineered in a commercial design. Furthermore, it was anticipated that if any problems occurred, they would likely be related to the burner (the least developed system component). However, the coal handling/feeding sub-system as it related to boiler system operability proved to be a critical component during initial testing. Some of the key system modifications and operational problems relating to the Penn State boiler are discussed below.

TCS Mill

The TCS mill and booster fan operated well without constant supervision. Initial system testing, however, revealed a coal settling problem in the mill outlet duct. This problem was corrected by a specially designed diffuser/transition section fitted to the mill exit. In addition, a detailed experimental study was carried out to characterize the effect of mill air flow rate and mill speed, on coal particle size distribution (PSD) and top size for the two coals tested. This was done as part of an effort to determine the milling conditions necessary to reduce the coal PSD and top size in order to achieve maximum coal combustion efficiency. In addition, the results were used to evaluate the feasibility for external classification to reduce the coal top size. The mill speed was a most important parameter to obtain the desired coal PSD. The results from these tests were used to optimize the mill settings for coal fineness during the experimental test program. Table 2 presents typical optimized mill operating conditions.

Table 2 Mill Performance Summary

- Typical mill air flow rate: 370-400 acfm
- Typical coal feed rate: 16.5- 18.5 lb/min

Particle Size (microns)	Brookville Seam Coal	Kentucky Coal
Top Size	190-300	250-275
D_{80}	50-70	50-70
D_{50}	25-30	25-30

Furnace Modifications

The furnace geometry was slightly altered during the test program by installing a ceramic wall at the exit of the radiant section of the boiler. The basic idea was to improve carbon burnout by making better use of the entire boiler volume through changing the gas patterns and temperature profile in the boiler. This was done because analytical (CFD) modeling showed that the flame was skewed from the burner to the furnace outlet and that the entire furnace volume was not being effectively used (Model results were subsequently verified by suction pyrometry).

Boiler System Operability

During the initial testing period, a number of operational problems involving the coal handling and boiler system were encountered. They were primarily related to the weather (cold, snow), the coal (particle size, moisture content), the burner/boiler system (unstable/ low u.v. flame scanner signal), or mechanical difficulties (feedwater pump, steam valves). With the exception of the coal handling problems caused by high moisture, these problems were all addressed and solved during the shakedown test series. The coal moisture problems will be fully addressed prior to beginning the 1000 hour demonstration test (Task 5).

C) SUMMARY OF EXPERIMENTAL RESULTS

Under the 400 hour test program, Brookville Seam and Kentucky coals were evaluated, the furnace geometry was modified by installing a ceramic wall, two coal guns (the RO-II with and without a coal deflector/accelerator and the I -Jet) were tested, and the operating conditions and without a coal deflector/accelerator and the I -Jet) were tested, and the operating conditions (excess air and firing rate) were varied. During the course of the long term coal only tests, no support fuel was required and the burner operated with excellent ignition stability. A typical summary of the microfine coal firing (both coals) is given in Table 3.

Table 3 Microfine Coal Firing Results

Boiler Operation:	
Steam Flow Rate (lb/hr)	13,240
Boiler Efficiency (%)	84.1 (3% O_2)
Combustion Performance	
Carbon Conversion Efficiency (%)	95.3
NOx at 3% O_2 (ppm)	413 (0.56 lb/MBtu)
Burner Pressure Drop (in H_2O)	8

During this test program, key performance variables were monitored in detail: boiler efficiency, combustion efficiency, and NOx emissions. A summary of the results involving these parameters follows.

Boiler Thermal Performance
Boiler thermal performance when firing micro-fine coal was essentially comparable to that achieved when firing natural gas. In fact, because of the greater latent heat loss when burning natural gas (greater formation of water due to higher hydrogen content), firing micro-fine coal actually gave slightly higher boiler efficiencies despite the need to run at higher excess air levels.

During the relatively short operating periods, usually less than 16 hours, ash deposits did not cause significant changes to the boiler thermal performance. It is recognized, however, that longer term operation could result in greater build-up of ash deposits which could impact heat transfer. Because of the relatively short duration of the tests, any build-up of ash deposits would slough off when the boiler was shut down. A better test of the possible impact of ash deposits will occur during the long term demonstration phase of the work (Task 5.0).

NOx Emissions
The NOx emissions target was 0.6 lb NOx per million Btu fired; this translates to about 450 ppm at 3% O_2. Testing with 100% microfine coal showed that this target was achieved (in general a NOx emissions value of 0.56 lb NOx per million Btu was routinely met) while meeting nearly all other required conditions. It is acknowledged that the optimum conditions for low NOx will generally exacerbate carbon conversion efficiencies. Indeed, this was the case with the HEACC burner and the challenge was to find a reasonable balance between meeting the NOx target while not aggravating the carbon conversion efficiency.

Combustion Efficiency
The target for combustion efficiency was 98%. The highest combustion efficiency obtained during the test program was slightly over 96%. However, this value was not compatible with meeting the NOx target, and was not able to be routinely repeated. A value of 95% combustion efficiency was able to be routinely achieved, and was compatible with meeting the NOx target.

Considerable effort was spent in trying to determine how combustion efficiency might be improved to meet the target. The challenge to meet the combustion efficiency targert of 98% is, indeed a very difficult one. The bulk boiler residence time is about 0.7 seconds. Further complicating the task is the aspect ratio of the boiler, i.e. the length of the boiler is not very much greater than its height or width (approximatelt 8 ft long x 8 ft high x 6 ft wide). It is aggravates the situation. Burner modifications are being looked at which might increase the particle residence time.

Coal particle size distribution was also evaluated, the premise being that carbon content must be directly proportional to particle size. While the larger particle size fraction of the collected particulate (fly ash) did contain higher carbon contents than the smaller size fractions, the differences were not as great as expected. For example, it would not be possible to dramatically reduce the carbon content of fly ash by eliminating coal particles larger than 150 microns.

SYSTEM ECONOMICS

This phase of the work involved an economic evaluation of coal firing for existing small industrial boiler installations. In addition to a base case evaluation (the 15,000 lbm/hr natural gas fired Penn State boiler), various economic sensitivity studies which provide insight into the economics for other unit sizes, fuel price scenarios, capacity factors and other variables were carried out. The primary objective of this analysis was to determine how the coal option compares with natural gas firing on an annual basis. With coal firing the capital costs for the retrofit modifications as well as some additional operating and maintenance costs must be justified by the savings in fuel costs. The evaluation summarized here defines the incremental costs and savings on an annual basis as a result of the use of coal as a substitute for natural gas firing. The first year incremental operation and maintenance cost savings and the total retrofit capital requirement were then used to determine a simplified payback period. The details of the data and results have been summarized in a recent publication (Patel, et al., 1995).

KEY RESULTS FROM THE ECONOMIC EVALUATION

A series of economic comparisons were carried out for the base case and other systems involving different economic input parameters. For these studies a range of differential fuel costs were used, and other sensitivity studies were carried out to determine the effect of unit size, annual operating time, and carbon heat loss on simplified pay back time. Figures 3 to 5 show the results of these sensitivity studies. In addition to differential fuel costs (see Fig. 3), other sensitivity variables studied were shown to have significant effects on payback period. As shown in Fig. 4, increasing unit size is shown to quickly improve the economics. Also, as shown in Fig. 5, changes in the annual operating time from 4000 to 8000 hrs/yr showed significant effects on payback period. Typically industrial boilers have very high capacity factors (the base case for this study used 7000 Hrs/yr (equivalent to an 80 percent capacity factor)). Fig. 8 is of most interest as it shows that variations in carbon heat loss (combustion efficiency) have no significant effect on payback period for the range studied (2 to 6%).

Although this analysis was done relative to natural gas as the base fuel, the results can also be generally applied to oil firing as well. By knowing the differential fuel cost the payback period can be approximated from the attached curves. Although boiler efficiency with oil firing is typically about 5 percent better than with natural gas, the effect on payback period is relatively insignificant as was shown by the results of the carbon heat loss sensitivity study.

CONCLUSIONS/ RECOMMENDATIONS

The following specific conclusions are based on the results of the coal fired testing at Penn State and the initial economic evaluation of the HEACC system:

- A coal handling/ preparation system can be designed to meet technical requirements for retrofitting micro-fine pulverized coal.

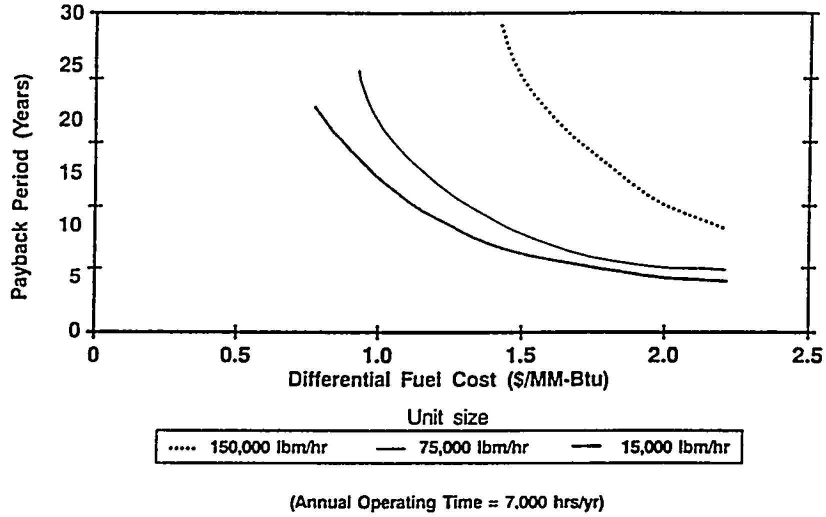

Figure 3 Payback Period as a function of Differential Fuel Cost and Unit Size

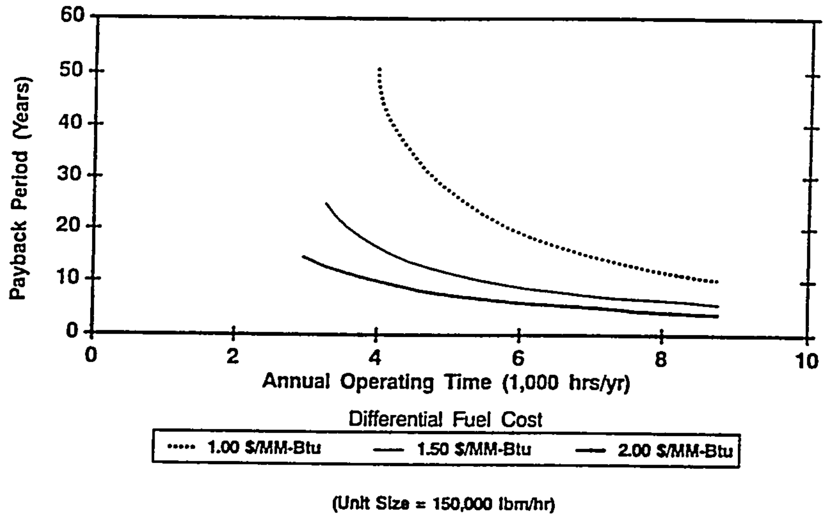

Figure 4 Payback Period as a function of Annual Operating Time

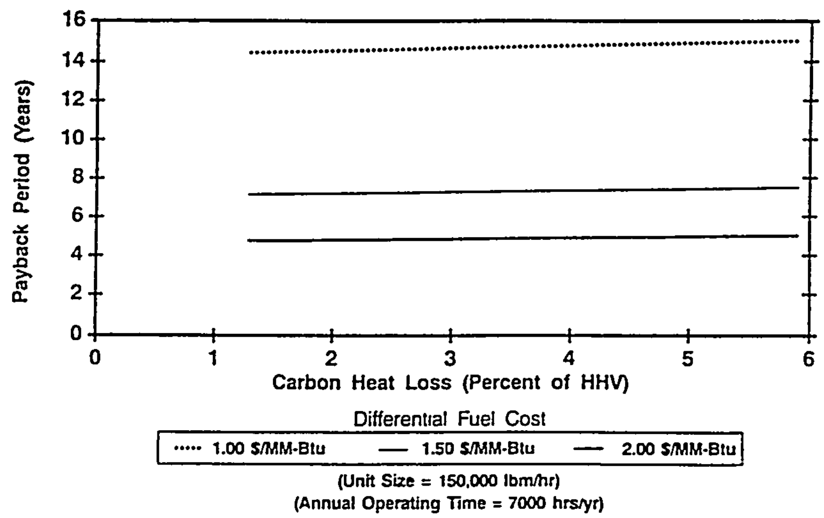

Figure 5 Payback Period as a function of Carbon Heat Loss

- The boiler thermal performance met requirements
- Combustion efficiencies of 95% could be met on a daily average basis, somewhat below the target of 98%
- NOx emissions can meet the target of 0.6 lb/million Btu
- The economic payback was very sensitive to fuel differential cost, unit size, and annual operating hours

As a result of recent long term tests using micronized coal (in another program), Penn State has experienced some convective pass ash deposition problems. To alleviate this problem they are planning to install additional soot blowers. Also, as a result of problems encountered during the 400 hour testing, the following modifications are planned for the Penn State system:

Coal feeding improvements
a) Improved raw coal/ storage and transport
b) Redesign/installation of a surge bin bottom
c) Installation of a gravimetric feeder
Monitoring of ash deposit effects
a) Air sparge/soot blower systems
b) Monitoring effects on heat transfer in the furnace and the convective pass
c) The use of ash deposition probes

In addition, ABB CE plans to modify the burner for more precise aerodynamic control of the fuel and air streams to improve the combustion efficiency and NOx emissions. Based on the results summarized in this paper the ABB/Penn State team and DOE/PETC have decided to conduct a 1000 hr demonstration (Task 5) of this program; it is currently scheduled to begin in July 1995.

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Table 1. Burner Characterization Summary

Date	Time	O2 (%)	CO (ppm)	CO2 (%)	NOx (ppm)	SO2 (ppm)	Firing Rate (MM Btu/h)	Steam Flow (lb/h)	UV signal	Steam Press (psig)	Windbox P (in W.C.)	Static Pressure Primary	Static Pressure Secondary	Static Pressure Tertiary	Comb. Air (scfm)	Comb Air (F)	Mill Air Flow (scfm)	Boiler Outlet (F)	BH Inlet (F)	Conv. Pass (F)	Swirler Settings Primary	Swirler Settings Secondary	Swirler Settings Tertiary	Coal Gun Position	Gas Gun Position	Observations
7/24/85 (Gas firing)	1200	2.05	39	10.47	38		13.1	12,588	8 to 9	210	7.6				3,890	381	NA	528	341		open	open	closed	out	-4	detached flame, breaching pulsing
	1220	2.80	37	10.02	38		13.1	12,013	10.0	210	7.3				3,910	380		530	344		open	open	open 1/4	out	-4	detached flame, bright blue
	1250	1.00	305	11.00	37		13.1	12,250	8 to 8	207	8.0				3,540	381		524	340		open	open	closed	out	-4	detached flame, breaching pulsing
	1415	1.00	78	11.01	43		18.95	15,488	8.5 to 9.5	215	5.6				4,880	394		570	369		open	open	open	out	-3	detached flame, boiler stable
	1450	1.40	52	10.84	42		18.95	15,500	9 to 10.5	217	5.3				4,880	395		572	373		open	open	open	out	4	detached flame, blue color, boiler stable
	1535	1.10	88	10.87	44		18.95	15,751	9.5 to 11	215	5.4				4,880	393		571	372		open	open	open	out	1	detached flame, blue color, boiler stable
	1552	1.00	88	11.00	44		18.95	15,500	9.5 to 10.5	220	5.5				4,850	382		572	372		open	open	open 85%	out	4	detached flame, blue color, boiler stable
	1615	0.90	65	11.00	44		18.95	15,013	9 to 10	218	5.7				4,570	387		573	372		open	closed	open	out	4	more attached, visible portion of flame closer to burner, blue flame, boiler stable
	1700	0.80	63	11.10	35		8.9	8,850	5 to 8	200	1.5				2,400	368		481	318		open	closed	open	out	4	flame has mixture of yellow and blue, flame closer to quarl, boiler stable
	1720	2.80	43	10.10	38		9.2	8,725	7 to 8.5	200	3.2				2,810	382		483	318		open	open	open 25%	out		slightly detached flame, blue, boiler stable
7/25/85 (Gas firing)	0930	2.80	108	8.50			13.1	12,613	8.0	210	7.0				4,060	372		531	338		open	closed	open 50%	out	-1	attached flame, short & wide blue flame, front wall radiant
	0955	2.80	30	9.48	40		13.3	12,575	9.0	210	7.1				4,050	374		533	342		open	open	open 50%	out	-4	detached flame, short but not as wide
	1045	1.48	37	10.48	40		18.95	15,713	10 to 11	213	3.4				4,720	388		568	370		open	open	open	out	-4	detached flame, blue color, boiler stable
	1210	2.05	130	10.17	47		17.1	15,750	11.0	217	5.5				4,680	390	183	576	376		open	open	open	out	4	flange removed from mill inlet, flame on quarl, yellow in front, blue in firebox, boiler stable
(75% load)																										
3% O2	1450	3.08	45	9.87	44		13.2	12,256	8.5 to 10	210	8.7				3,920	387		531	348		open	open	open 25%	out	-4	mill and fan off, blue flame, boiler stable
2% O2	1530	2.13	40	10.14	44		13.2	12,484	8 to 9.5	207	8.1				3,740	371		528	344		open	open	open 25%	out	-4	flame transparent (detached), blue color, boiler stable
1% O2	1600	1.25	65	10.55	43		13.2	17,064	7.5 to 9.5	210	5.5				3,560	372		525	343		open	open	open 25%	out	-4	detached flame, blue color, boiler stable
7/26/85 (Gas firing; 100% load)	1010	1.55	33	11.06	21		16.9	15,039	10 to 12	215	5.5				4,780	388		567	384		open	open	open	out	4	detached flame, blue color, boiler stable
	1240	1.18	47	11.14	20		17.1	15,078	9 to 10.5	217	5.5				4,890	382		570	371		open	open	open	out	0	detached blue flame, boiler stable
7/27/85 (Coal firing)	1445	2.53	369	16.20	383	430	14.8			200	4.0						371			931	open	open	closed	-5	-9.5	
	1453	3.20	450	16.34	396	421	14.8	11,193	10 to 11	200	3.5				2,880	393	350	517	348		open	open	open 25%	-5	-9	
	1515	2.91	422	15.45	350	415	14.8	10,797	8.5 to 11	200	3.1				2,870	393	350	518	350		open	open	open 25%	-5	-9	
	1519	2.88	778	15.80		419	14.8	11,060	8 to 9	205	2.5				2,800	393	354	518	350		open	open	open 75%	-5	-9	
	1537	3.18	348	15.47		404	14.8	10,660	8.5 to 10	200	3.2				2,970	395	365	530	352		open	open	open 50%	-5	-9	
	1557	3.08	350	16.05		410	14.8	10,910	9 to 10.5	200	4.0				3,020	398	366	538	356		open	open	open 25%	-5	-9	
7/28/85 (Coal firing)	1300	3.04	183	15.14	322	388	15.4	12,470	10.0	200	7.6				3,330	409	384	584	389		open 50%	open	closed	-5	-9	
	1321	3.50	202	15.07		373	15.4	12,134	7.5 to 9	203	7.2				3,410	412	382	589	372		open	open	closed	-5	-9	
	1333	3.02	241	15.57		383	15.4	12,832	7.5 to 10	200	8.1				3,430	414	356	571	372		open	open	open 25%	-5	-9	
	1343	2.72	270	15.78		394	15.4	12,813	8.5 to 10	205	4.1				3,410	415	358	589	373	1,045	open	open	open 50%	-5	-9	
	1359	3.09	205	15.37		383	15.4	11,885	8.5 to 10	200	5.1				3,490	418	388	575	375	1,044	open	open	open 25%	-5	-9	
	1412	3.03	252	15.08		383	15.4	11,774	8.5 to 9.5	205	5.3				3,400	413	358	573	374	1,042	open	open 50%	open 25%	-3	-9	
	1433	3.06	276	14.98		378	15.4	13,350	7.5 to 9	200	6.0				3,340	414	358	574	376	1,050	open 50%	open	open 25%	-3	-9	
	1510	2.71	219	15.94		388	15.4	13,925	7.5 to 9	200	6.1				3,310	419	382	582	375	1,067	open 50%	open 50%	open 25%	-3	-9	
	1522	2.94	227	15.97		389	15.4	12,818	7.5 to 9	200	6.4				3,370	417	352	590	380	1,079	open 50%	open 50%	open 25%	-3	-9	
	1536	3.03	201	15.03		375	15.4	13,394	10 to 11	210	6.7				3,710	419	387	602	383	1,085	open 50%	open 50%	open 25%	-3	-9	
7/31/85 (Coal firing)	1535	2.72	153	16.18	580		15.4	11,750	10.0		6.3				3,530	420	372	593	381		open 50%	open 50%	open 50%	-5	-8	lost rotary valve at 1615
8/1/85 (Gas firing)	1602	1.35	81	11.41	48		8.5	8,480	8.5	205	1.3				2,130	375		471	321	813	open	open	open 75%	out	4	
	1700	1.48	57	11.40	45		8.5	9,320	8.0	200	1.8				2,130	367		469	315	812	open	open	open 75%	out	4	
8/3/85 (Coal firing)	1107	2.68	198	15.62	433	413	15.4	13,000	11.0	207	7.2				3,210	404	350	520	354		closed	closed	closed	-7	-7	
	1134	2.72	198	15.57	498	401	15.4	13,112	11.5	207	8.0				3,340	401	357	542	361	1,013	closed	closed	closed	-7	-7	
	1205	2.38	190	15.53	477	408	15.4	12,500	10.0	205	7.8				3,410	401	322	538	362	1,017	closed	closed	closed	-7	-7	
	1223	3.22	183	15.35	457	392	15.4	12,850	9.0	205	7.8				3,350	401	315	543	362	1,015	closed	closed	closed	-7	-7	
	1253	2.85	188	15.37	478	394	15.4	13,033	11.0	203	7.9				3,310	402	307	548	362	1,033	closed	closed	closed	-7	-7	
	1317	2.80	158	15.75	508	401	15.4	13,050	11.5	205	8.0				3,360	402	288	550	365	1,038	closed	closed	closed	-7	-7	
	1347	2.12	515	16.36	458	478	15.4	12,870	10.0	205	7.2				3,200	408	300	547	364	1,035	closed	closed	closed	-7	-7	
	1441	2.87	202	15.57	488	408	15.4	12,880	11.0	203	4.4				3,310	414	288	581	375	1,058	open 75%	closed	closed	-7	-7	
	1501	3.20	187	15.37	478	401	15.4	12,500	12.0	203	3.3				3,410	416	302	571	372	1,060	open	closed	closed	-7	-7	
	1540	2.64	169	15.50	478	408	15.4	12,990	12.0	202	3.5				3,260	392	272	521	358	1,039	open	closed	closed	-7	-7	
	1615	1.64	188	16.24	480	420	15.4	13,830	12.0	202	3.8				3,370	395	276	528	358	1,026	open	closed	closed	-7	-7	
	1640	2.40	188	16.33	488	417	15.4	14,100	12.0	203	7.2				3,600	395	288	543	362	1,031	open 75%	closed	closed	-7	-7	
	1700	2.74	174	15.71	447	433	15.4	14,300	12.0	207	4.4				3,680	402	284	558	367	1,048	open	closed	closed	-7	-7	
	1730	2.79	171	15.41	417	425	15.4	14,300	12.0	204	4.4				3,840	408	382	574	377	1,098	open	closed	open 50%	-7	-7	
	1744	4.15	171	14.35	558	388	15.4	14,000	12.0	202	4.1				3,850	414	378	581	382	1,087	open	closed	open 50%	-7	-7	
	1830	4.90	183	13.80	472	392	15.4	12,708	12.0	205	4.1				3,840	418	377	587	387	1,107	closed	closed	open 50%	-7	-7	
	1845	4.58	235	14.19	384	348	15.4	12,705	12.5	205	4.7				3,800	412	372	573	380	1,107	closed	closed	open	flush	-7	
	1900	4.39	210	14.88	402	344	15.4	13,138	12.5	202	4.3				3,680	412	332	575	376	1,106	closed	closed	open	2	2	
	1915	3.84	224	14.80	472	392	15.4	12,583	11.5	202	4.3				3,500	412	340	573	375	1,102	closed	closed	closed	2	2	
	1930	4.38	187	12.92	450	340	15.4	13,295	9.5	202	8.8				3,700	412	342	583	378	1,113	closed	closed	open 25%	2	2	
	1945	3.78	208	15.18	412	383	15.4	13,097	11.0	200	7.9				3,280	408	341	572	378	1,097	open	closed	closed	2	0	
	2000	3.28	183	15.00	470	392	15.4	12,896	11.0	200	8.0				3,440	405	331	581	378	1,101	open	closed	closed	0	0	
	2015	3.04	154	15.66	633	388	15.4	13,045	11.9	210	8.2					405	344	588	379	1,099	open	closed	closed	2	2	
8/6/85 (Coal firing except for 1210 which was gas firing)	1210	1.52	171	11.29	119		10.0	15,081	12.0	215	8.8				4,450	400	0	560	369	1,138	open 75%	closed	open	flush	-9	
	1243	2.91	389	16.23	388	423	15.4	11,239	13.0	195	3.0				3,210	409	345	545	359	1,034	closed	closed	open	42.25	-9.5	
	1805	3.19	305	16.21	344	484	15.4	12,717	12.5	200	3.2				3,220	412	314	551	381	1,028	closed	closed	open	42.25	-9.5	
	1830	2.44	721	16.94	357	523	15.4	12,940	12.8	200	3.2				3,220	415	291	584	364	1,089	closed	closed	open	42.25	-9.5	
8/8/85 (Coal firing)	0900	3.85	145	15.78	333	513	15.8	12,500	12.0	202	3.4				3,460	408	328	595	367	1,078	closed	closed	open	42.25	-9.5	
	0930	3.85	234	16.09	348	528	15.8	13,500	12.5	188	3.7				3,650	422	343	587	375	1,127	closed	closed	open	42.25	-9.5	
	1000	3.99	289	15.68	382	516	15.8	13,178	13.0	185	4.0				3,670	428	357	597	382	1,149	closed	closed	open	42.25	-9.5	
	1030	3.41	174	15.48	383	5123	15.8	13,384	13.0	185	4.0				3,720	433	351	608	385	1,159	closed	closed	open	42.25	-9.5	
	1100	2.47	208	15.83	371	525	15.8	13,438	13.0	200	4.0				3,870	435	352	612	389	1,176	closed	closed	open	42.25	-9.5	
	1130	3.31	187	15.88	393	523	15.8	13,777	12.0	197	4.0				3,870	439	353	620	394	1,192	closed	closed	open	42.25	-9.5	
	1200	2.33	204	15.68	384	500	15.8	14,081	13.0	200	3.8				3,580	400	337	532	383	1,071	closed	closed	open	42.25	-9.5	
	1230	3.09	179	15.78	415	517	15.8	13,217	13.0	200	3.8				3,550	401	313	545	382	1,048	closed	closed	open	42.25	-9.5	

Table 1. Burner Characterization Summary

Date	Time	O_2 (%)	CO (ppm)	CO_2 (%)	NO_x (ppm)	SO_2 (ppm)	Firing Rate (MM Btu/h)	Steam Flow (lb/h)	UV signal	Steam Press (psig)	Windbox P (in W.C.)	Static Pressure			Comb. Air (scfm)	Comb Air (F)	MH Air Flow (scfm)	Boiler Outl (F)	BH Inlet (F)	Conv. Pass (F)	Swirler Settings			Coal Gun Position	Gas Gun Position	Observations
												Primary	Secondary	Tertiary							Primary	Secondary	Tertiary			
	1400	2.27	108	16.48	886	552	15.8	14,374	11.5	200	8.2				3,600	407	328	594	379	1,102	open	closed	closed	42.25	-0.5	
	1430	2.37	117	16.09	875	553	15.8	13,962	12.0	200	8.2				3,580	409	315	591	384	1,112	open	closed	closed	42.25	-0.5	
	1500	2.52	114	16.38	701	557	15.8	14,704	11.5	200	8.2				3,580	413	330	599	388	1,130	open	closed	closed	42.25	-0.5	
	1530	3.08	118	15.92	888	540	15.8	14,338	11.5	195	8.2				3,350	418	319	605	391	1,125	open	closed	closed	42.25	-0.5	
	1600	2.80	128	16.66	874	553	15.8	14,031	11.5	197	8.3				3,540	422	331	612	398	1,138	open	closed	closed	42.25	-0.5	
8/10/95 (Coal firing except for 1100 which was natural gas firing)	1100	1.63	160	11.51	420	5	17.05	10,530	6.0	191	6.0				4,860	380	nm	588	378	1,091	100%	100%	100%	0	4	
	1345	3.33	139	15.51	420	520	15.4	14,217	10 to 11	190	4.5				3,590	401	375	557	386	1,030	open	closed	open	33.25	-7	
	1415	3.45	130	15.78	440	524	15.4	14,606	10 to 11	195	4.8				3,670	407	370	584	373	1,028	open	closed	open 75%	33.25	-7	
	1445	3.61	119	15.84	453	530	15.4	14,466	10 to 11	195	4.4				3,630	412	372	571	377	1,035	open	closed	open 50%	33.25	-7	
	1505	3.19	125	15.62	441	543	15.4	14,035	10 to 11	195	6.5				3,680	413	371	573	378	1,031	open	closed	open 25%	33.25	-7	
	1530	3.99	125	15.72	475	534	15.4	14,453	10 to 11	190	7.4				3,660	412	378	580	380	1,045	open	open	open 12%	33.25	-7	
	1555	3.62	127	15.69	488	537	15.4	14,470	10 to 11	195	6.8				3,850	415	382	589	384	1,066	open	closed	open 50%	33.25	-7	
	1620	4.19	133	14.81	411	520	15.4	14,423	10 to 11	190	5.0				3,690	420	389	591	387	1,088	closed	closed	open	33.25	-7	
	1635	3.83	137	15.02	387	530	15.4	14,539	12	195	5.2				3,660	421	372	592	387	1,070	closed	closed	open	37.5	-8	
	1650	3.04	149	15.73	378	559	15.4	14,034	12.5	195	5.2				3,700	421	381	592	387	1,071	closed	closed	open	31	-5	
	1700	3.73	145	15.10	392	534	15.4	14,293	12.5	189	5.3				3,780	422	370	598	389	1,076	closed	closed	open	31	-5	
	1735	3.70	180	15.09	353	533	15.4	13,389	10.5	185	4.8				3,740	424	369	601	391	1,049	closed	closed	open	27	2	
8/21/95 (Gas firing)	1830	2.04	76	10.87	49	3	17	17,270	11.0						4,499	407	400	587	394	1,098	100%	100%	100%			
8/22/95 (Gas firing)	0935	2.43	55	11.06	56		16	15,000			6.7	3.0	-1.3	3.2	4,360	388		577			100%	100%	50%	33.375	4	
	0950	2.13	51	11.11	65		16	15,528			5.2	2.7	-1.4	3.1	4,333	400		579		1,139	100%	0%	100%	33.375	4	more attached, burning into coal annulus, very little visible narrowing or widening
	1030	2.03	53	11.25	85		16	15,055			2.8	2.7	-1.4	3.2	4,352	403		579		1,138	100%	0%	90%	33.375	3	slightly longer
	1036	1.21	188	11.76	59		16.1	15,776			4.1	3.6	-1.6	3.2	4,150	398				1,119	100%	10%	40%	33.375	3	burning in coal gun,photohelic calmer, wider, slightly shorter
	1055	0.58	844	12.02	57		16	15,682			4.4	3.8	-1.8	3.2	4,000			572		1,126	100%	10%	75%	33.375	3	4" shorter, less pulsing, moved back, 2 volts lower UV,burning in coal gun
	1115	1.48	72	11.85	58		16.06	15,564			6.9	3.1	-1.2	3.3	4,726			571		1,129	100%	100%	33%	33.375	3	lower UV, flame moving outward, shorter flame
	1150	1.14	144	11.83	53		16	15,039			7.2	3.2	1.7	3.4	4,180			571		1,126	100%	50%	33%	33.375	3	
	1200	1.00	182	11.52	58		16	15,732			6.9	3.2	-1.4	3.3	4,220			574		1,121	100%	85%	80%	33.375	3	
	1205	1.01	152	11.31	60		16	15,899			6.9	3.1	-1.0	3.3	4,190			574		1,131	100%	100%	90%	33.375	3	
	1230	1.02	78	11.73	61		16	15,030			6.7	3.6	-1.5	3.3	4,098			575		1,117	100%	0%	80%	33.375	3	
	1245	1.93	48	11.30	67		16	15,497			5.3	2.7	-1.2	3.3	4,780			570		1,072	100%	0%	100%	33.375	3	
	1315	1.99	80	11.36	64		16	15,381			4.7	2.4	-1.2	2.8	4,485			570		1,076	100%	50%	100%	33.375	3	
	1320	1.96	176	11.31	63		16	15,231			4.6	2.2	-0.8	3.7	4,280			577		1,078	100%	100%	90%	33.375	3	
	1415	1.06	89	11.76	61		16	15,380			7.0	4.2	-0.8	3.8	4,006			570		1,070	100%	100%	30%	38.375	3	
	1430	0.94	88	11.78	58		16	15,282			7.0	4.2	-0.8	3.5	4,006			570		1,071	100%	100%	30%	38.375	-3	
	1525	2.00	58	11.28	56		16	14,934			6.6	3.3	-3.8	0.8	4,445			575		1,085	100%	100%	30%	32.375	4	
8/23/95 (Gas firing 0817 to 1125 and coal firing 1420 to 1715)	0817	1.61	35	11.50	60		16	14,843			5.4	2.2	-0.9	2.8	4,260	405		577		1,087	100%	100%	80%	29.5	3	
	0832	0.99	151	11.82	57		16.1	14,770			5.4	2.6	-0.9	2.8	4,140	408		574		1,085	100%	100%	90%	29.5	3	
	0858	1.56	31	11.59	35		16.1	15,119			6.9	3.3	-1.0	3.4	4,320	395		576		1,078	100%	100%	30%	29.5	3	
	0912	0.96	112	11.82	37		16.1	15,015			6.6	3.3	-1.0	3.1	4,120	402		575		1,076	100%	100%	30%	29.5	3	
	0940	1.61	31	11.50	58		16.1	16,063			7.0	1.6	-0.6	3.6	4,180	398		578		1,087	100%	100%	30%	29.5	3	
	1021	2.04	21	11.30	72		16.17	15,741			6.0	2.2	-1.0	3.4	4,380	405		584		1,093	80%	100%	40%	29.5	3	
	1041	1.12	43	11.78	58		16.21	16,010			7.0	3.5	-1.2	3.5	4,200	403		581		1,088	100%	0%	75%	29.5	3	breeching rumbling
	1051	0.40	1880	12.08	48		16.15	16,258			7.5	3.5	-1.2	3.4	4,030	399		574		1,079	100%	0%	50%	29.5	3	
	1059	0.99	60	11.64	49		16.17	15,819			7.1	3.4	-0.8	3.4	4,120	398		576		1,080	100%	100%	75%	29.5	3	
	1125	1.20	1888	11.30	53		16.2	15,537	12.5		6.0	1.3	0.0	3.1	4,090	409		576		1,120	100%	100%	25%	29.5	3	
	1420	3.72	231	15.46	131		15.7	12,136	12.0		4.2	1.7	-0.5	2.9	3,352	396	357	540		972	35%	100%	100%	29.5	3	yellow flame, rumbling stopped
	1440																				35%	100%	100% 25%	32		
8/24/95 (Coal firing)	0912	3.17	231	15.29	392	555	15.73	13,053	17.5	190	4.5	1.8	0.0	2.2	3,450	419	380	580	373	1,062	100%	100%	50%	-3	out	
	941	2.31	201	15.36	459	551	15.73	14,020	10	188	7.8	3.4	0.0	2.8	3,350	420	384	584	381	1,068	100%	100%	0%	-3	out	
	1042	2.87	123	15.50	455	551	15.73	14,139	12.0	191	7.8	3.0	0.0	2.7	3,420	399	384	547	385	878	100%	100%	0%	-3	out	
	1120	2.84	130	15.02	381	531	15.73	13,675	10.0	185	8.5	3.4	1.0	2.7	3,493	392	372	550	384	881	100%	0%	0%	-3	out	
	1151	2.86	161	15.09	498	531	15.73	14,145	9.5	184	6.4	3.4	1.2	2.9	3,530	392	353	552	387	881	100%	0%	0%	-4.5	-9	
	1231	2.55	133	15.75	487	531	15.73	14,797	12.5	197	4.0	1.4	-0.6	2.5	3,480	405	325	559	371	1,008	100%	0%	50%	-9	-9	
	1238	2.77	155	15.78	378	542	15.73	14,595	12.0	195	3.3	1.1	-0.7	2.1	3,550	406	318	568	374	1,011	100%	0%	100%	-9	-9	
	1327	2.93	387	16.16	379	535	15.73	13,834	12	183	3	1.0	-0.8	1.9	3,370	407	328	582	374	887	100%	0%	100%	-13.5	-9	
	1503	uniform testing																								
8/25/95 (Coal firing)	uniform testing																									
8/28/95 (Coal firing)	uniform testing																									
8/29/95 (Coal firing)	1030	2.79	133	15.21	438	525	15.8	12,547	13.0	191	4.1		0.3	2.2	3,498	418	399	578	379	1,052	100%	100%	50%	-10.5	-9	
	1100	3.49	138	15.31	430	529	15.6	13,074	12.0	189	4.3	1.1	0.4	2.2	3,480	418	399	588	384	1,060	100%	100%	50%	-10.5	-9	
	1130-1700	uniform testing																								
8/30/95 (Coal firing)	uniform testing																									
8/31/95 (Coal firing)	uniform testing																									
9/5/95 (Coal firing)	1130	uniform testing																								
	1400	3.85	87	15.84	478	512	15	13,822	12.5	190	5.1	0.8	0.2	2.8	3,630	414	378	548	384	991	100%	100%	50%	-10.5	-9	
	1430	4.05	74	15.54	500	519	15	14,118	13.5	185	4.7	0.8	0.2	2.7	3,600	408	386	557	381	1,007	100%	100%	50%	-10.5	-9	

Table 1. Burner Characterization Summary

Date	Time	O2 (%)	CO (ppm)	CO2 (%)	NOx (ppm)	SO2 (ppm)	Firing_Rate (MM Btu/h)	Steam_Flow (lb/h)	UV_signal	Steam_Press (psig)	Windbox_P (in W.C.)	Static Pressure Primary	Static Pressure Secondary	Static Pressure Tertiary	Comb._Air (scfm)	Comb.Air (F)	MM_Air_Flow (scfm)	Boiler_Outlet (F)	BH_Inlet (F)	Conv._Pass (F)	Swirler Settings Primary	Swirler Settings Secondary	Swirler Settings Tertiary	Coal Gun Position	Gas Gun Position	Observations
9/6/95	0815	4.05	132	15.73	439	531	15	12,899	13.5	182	4.8	0.3	0.0	2.5	3,440	408	379	570	374	1,005	100%	0%	70%	-10.5	-9	
(Coal_firing)	0845	3.89	172	15.32	406	519	15	13,513	13.5	186	4.7	0.2	0.1	2.7	3,500	420	387	588	387	1,048	100%	100%	70%	-10.5	-9	
	1015	3.72	144	15.40	413	532	15	13,599	13.5	188	4.7	0.3	0.0	2.7	3,440	423	380	582	389	1,070	100%	0%	70%	-10.5	-9	
	1045	3.81	128	15.52	442	522	15	13,871	13.2	187	5.3	0.8	-0.3	2.7	3,330	420	381	603	394	1,091	100%	0%	50%	-10.5	-9	
	1115	3.52	186	16.02	443	513	15	14,400	13.2	184	5.3	0.8	-0.2	2.6	3,380	410	388	545	377	1,001	100%	0%	45%	-10.5	-9	
	1230	3.78	123	15.57	403	525	15	14,276	12.5	183	3.8	0.8	-0.2	2.3	3,430	412	370	574	386	1,031	100%	0%	100%	-10.5	-9	
	1445	4.01	151	15.80	452	483	15	14,534	12.5	179	4.2	0.2	-0.3	2.4	3,510	415	382	557	388	1,005	100%	0%	75%	-10.5	-9	
	1700	4.10	126	15.26	332	520	15	14,252	13.0	178	6.5	0.6	-0.8	2.3	3,500	426	394	603	402	1,091	100%	0%	25%	-10.5	-9	
	1815	3.13	121	15.90	600	540	15	14,030	13.0	181	6.7	1.2	-0.9	2.6	3,350	408	389	595	393	1,087	100%	0%	0%	-10.5	-9	
9/7/95	0930	3.57	119	15.59	414	530	15	13,240	13.0	182	3.3	0.8	-0.8	2.7	3,330	422	383	609	385	1,103	100%	50%	0%	-9	39.5	
(Coal_firing)	1130	3.72	104	15.44	528	515	15	13,332	13.0	183	2.8	0.8	0.2	2.6	3,280	407	382	588	379	1,037	100%	100%	0%	-9	39.5	
	1300	4.25	193	15.42	388	508	15	13,138	13.0	185	3.2	0.3	0.2	1.7	3,400	410	389	595	384	1,092	100%	100%	100%	-9	39.5	
	1500	3.89	111	15.70	415	526	15	13,048	13.0	181	3.4	0.5	-0.5	2.2	3,390	409	378	570	385	1,043	100%	50%	100%	-9	39.5	
	1630						15	--	13.0	180	3.7	0.4	-0.5	2.2	3,457	420	378	597	351	1,110	100%	0%	100%	-9	39.5	
	1900						15		13.0	183	3.3	0.3	-0.3	1.7	3,275	419	372	598	328	1,098	0%	100%	100%	-9	39.5	

Table 2. Summary of Natural Gas Baseline Testing

TEST/DESCRIPTION:	ABB COMBUSTION ENGINEERING BASELINE GAS SUMMARY				
	7/25/95	7/25/95	7/25/95	7/26/95	8/1/95
	3% O2	2% O2	1% O2	1% O2	1.5% O2
	Prim. Open	Prim. Open	Prim. Open	Prim. Open	Prim. Open
	Sec. Open	Sec. Open	Sec. Open	Sec. Open	Sec. Open
	Tert. 25% Op	Tert. 25% Op	Tert. 25% Op	Tert. Open	Tert.75% Op
	Gas Gun -4"	Gas Gun -4"	Gas Gun -4"	Gas Gun +4"	Gas Gun +4"
	Coal Gun Out	Coal Gun Out	Coal Gun Out	Coal Gun Out	Coal Gun Out
WATER/STEAM SIDE					
Steam flow rate; lb/h	12,404	12,387	12,411	15,659	8,609
Water temperature into boiler; °F	206	207	207	217	217
Drum pressure; psig	199	200	200	204	194
Calorimeter temperature; °F	304	304	304	317	313
Steam temperature; °F	378	379	379	391	387
Steam quality; %	99.48	99.50	99.50	100.23	99.37
Blowdown rate; lb/h	3,093	3,099	3,099	3,128	3,054
AIR,FUEL, FLUE GAS SIDE					
Natural gas flow rate; lb/h, MMBtu/h	567, 13.2	567, 13.2	567, 13.2	732, 17.1	367, 8.6
Coal flow rate; lb/h, MMBtu/h	Not Applicable (NA)	NA	NA	NA	NA
Furnace outlet temperature; °F	525	520	517	576	477
Gas temperature leaving air heater; °F	354	351	349	390	337
Air temperature entering air heater; °F	175	179	182	173	211
Air temperature leaving air heater; °F	383	384	384	409	385
Air temperature into boiler; °F	363	364	365	391	363
Ash content of particulate; %	NA	NA	NA	NA	NA
Carbon content of furnace ash; %	NA	NA	NA	NA	NA
HHV of fly ash; Btu/lb	NA	NA	NA	NA	NA
HHV of furnace ash; Btu/lb	NA	NA	NA	NA	NA
Combustion air flow; lb/h	11,112	10,577	10,092	13,279	6,765
Boiler draft; in H2O	-0.07	-0.07	-0.07	-0.08	-0.07
Boiler efficiency; %	82.84	82.94	83.14	83.03	83.61
Relative humidity, %	60	60	60	60	60
Mill air flow rate; lb/h	0	0	0	0	0
Mill outlet temperature; °F	77	77	72	115	80
Natural gas temperature; °F	80	80	80	85	98
EMISSIONS					
O2; %	3.1	2.1	1.1	1.5	1.8
CO; ppm	45	49	108	37	73
CO2; %	9.6	10.2	10.6	11.0	11.2
SO2; ppm	NA	NA	NA	NA	NA
NOx; ppm	44	44	43	26	48
Particulates; gr/SCF	NA	NA	NA	NA	NA
O2 before and after air heater; %,%	3.1, Not Measured(NM)	2.1, NM	1.1, NM	1.5, NM	1.8,NM
ECONOMIC ANALYSIS DATA					
ID fan power consumption; w/h	NM	NM	NM	NM	NM
FD fan power consumption; w/h	NM	NM	NM	NM	NM
Pulverizer power consumption; w/h	NA	NA	NA	NA	NA
Booster fan power consumption; w/h	NM	NM	NM	NM	NM
Ash collection power consumption; w/h	NA	NA	NA	NA	NA
Crusher power consumption; w/h	NA	NA	NA	NA	NA
Reddler conveyor power consumption; w/h	NA	NA	NA	NA	NA
Feed screw power consumption; w/h	NA	NA	NA	NA	NA
Feedwater pump power comsumption; w/h	NM	NM	NM	NM	NM
Total air usage; scfm (Pilot burner)	NM	NM	NM	NM	NM
Maximum load (based on 14,700 lb steam/h); %	84.38	84.27	84.43	106.52	58.56
Coal related downtime	NA	NA	NA	NA	NA

Table 3. Summary of Coal-Fired Testing

TEST/DESCRIPTION:	8/9/95	8/9/95	8/23/95	8/24/95	8/25/95
	Low-NOx	High Comb. Eff			
	Prim. Closed	Prim. Open	Prim. Open	Prim. Open	Prim. Closed
	Sec. Closed	Sec. Closed	Sec. 70%	Sec. Open	Sec. Closed
	Tert. Open	Tert. Closed	Ter. 50%	Tert. 50%	Tert. 50%
	Gas Gun -8.5°	Gas Gun -8.5°	Gas Gun 3°	Gas Gun -9°	Gas Gun -9°
	C. Gun 42.25°	C. Gun 42.25°	C. Gun 32°	C. Gun -10.5°	C. Gun -11°
WATER/STEAM SIDE					
Steam flow rate; lb/h	13,466	14,367	13,467	14,417	14,378
Water temperature into boiler; °F	218	219	208	207	207
Drum pressure; psig	191	186	187	183	187
Calorimeter temperature; °F	313	312	302	301	301
Steam temperature; °F	386	384	373	371	372
Steam quality; %	100.0	100.0	99.3	99.3	99.3
Blowdown rate; lb/h	3,027	2,985	2,994	2,967	2,999
AIR,FUEL, FLUE GAS SIDE					
Natural gas flow rate; lb/h, MMBtu/h	Not Applicable (NA)	NA	NA	NA	NA
Coal flow rate; lb/h, MMBtu/h	1,140;16.4	1,140;16.4	1,140;16.4	1,140;16.5	1,140;16.5
Furnace outlet temperature; °F	588	607	549	539	594
Gas temperature leaving air heater; °F	403	414	378	378	400
Air temperature entering air heater; °F	177	183	175	171	166
Air temperature leaving air heater; °F	427	436	404	395	421
Air temperature into boiler; °F	404	415	382	377	399
Ash content of particulate; %	47.55	61.61	30.82	49.94	45.02
Carbon content of furnace ash; %	NA	NA	NA	NA	NA
Coal combustion efficiency; %	94.1±1.2	97.2±0.5	89.2±1.3	95.3±0.6	94.5±0.6
HHV of fly ash; Btu/lb	NA	NA	NA	NA	NA
HHV of furnace ash; Btu/lb	NA	NA	NA	NA	NA
Combustion air flow; lb/h	14,615	14,011	14,403	14849	14,442
Boiler draft; in H2O	0.04	0.03	0.05	-0.04	-0.01
Boiler efficiency; %	83.44	85.75	80.36	84.7	83.48
Relative humidity, %	60	60	60	60	60
Mill air flow rate; acfm,lb/h	341;1,624	326;1,526	356;1,691	360;1,711	359;1,711
Mill outlet temperature; °F	231	243	211	206	206
Natural gas temperature; °F	85	93	88	91	79
EMISSIONS					
O2; %	3.5	2.7	3.4	3.8	3.3
CO; ppm;lb/MMBtu@3%O2	238;0.20	149;0.12	258;0.22	146;0.13	178;0.15
CO2; %	15.8	16.5	15.6	15.0	15.3
SO2; ppm;lb/MMBtu@3%O2	512;1.00	552;0.99	583;1.11	485;0.97	529;1.00
NOx; ppm;lb/MMBtu@3%O2	371;0.52	684;0.88	281;0.38	443;0.64	439;0.60
Particulates; gr/SCF	Not Measured (NM)	NM	NM	NM	NM
ECONOMIC ANALYSIS DATA					
ID fan power consumption; w/h	NM	NM	NM	NM	NM
FD fan power consumption; w/h	NM	NM	NM	NM	NM
Pulverizer power consumption; w/h	NM	NM	NM	NM	NM
Booster fan power consumption; w/h	NM	NM	NM	NM	NM
Ash collection power consumption; w/h	NA	NA	NM	NM	NM
Crusher power consumption; w/h	NA	NA	NA	NA	NA
Reddler conveyor power consumption; w/h	NA	NA	NA	NA	NA
Feed screw power consumption; w/h	NA	NA	NA	NA	NA
Feedwater pump power comsumption; w/h	NM	NM	NM	NA	NA
Total air usage; scfm (Pilot burner)	NM	NM	NM	NM	NM
Maximum load (based on 14,700 lb steam/h); %	91.6	97.7	91.6	98.1	97.8

Table 3. Summary of Coal-Fired Testing

TEST/DESCRIPTION:	8/28/95	8/29/95	8/30/95	8/31/95	9/5/95
	Prim. Open	Prim. Open	Prim. Open	Prim. Open	Prim. Open
	Sec. Open	Sec. Open	Sec. Open	Sec. Open	Sec. 50%
	Tert. 50%	Tert. 50%	Tert. 50%	Tert. 50%	Tert. 50%
	Gas Gun -9°	Gas Gun -9°	Gas Gun -9°	Gas Gun -9°	Gas Gun -9°
	C. Gun -10.5°	C. Gun -10.5°	C. Gun -10.5°	C. Gun -10.5°	C. Gun -10.5°
WATER/STEAM SIDE					
Steam flow rate; lb/h	14,039	13,938	14,139	13,601	13,122
Water temperature into boiler; °F	206	206	208	207	199
Drum pressure; psig	187	183	186	186	191
Calorimeter temperature; °F	300	301	302	302	301
Steam temperature; °F	372	371	373	372	374
Steam quality; %	99.3	99.3	99.4	99.3	99.3
Blowdown rate; lb/h	2,997	2,966	2,989	2,988	3,030
AIR,FUEL, FLUE GAS SIDE					
Natural gas flow rate; lb/h, MMBtu/h	NA	NA	NA	NA	NA
Coal flow rate; lb/h, MMBtu/h	1,140;16.5	1,140;16.5	1,140;16.5	1,140;16.5	1,098;15.6
Furnace outlet temperature; °F	562	561	566	571	571
Gas temperature leaving air heater; °F	386	389	390	391	389
Air temperature entering air heater; °F	168	177	173	175	171
Air temperature leaving air heater; °F	406	406	406	411	403
Air temperature into boiler; °F	383	387	385	389	377
Ash content of particulate; %	47.90	50.20	53.13	50.95	61.08
Carbon content of furnace ash; %	NA	NA	NA	NA	NA
Coal combustion efficiency; %	94.3±1.1	95.4±0.2	95.9±0.8	95.5±0.4	97.5±0.8
HHV of fly ash; Btu/lb	NA	NA	NA	NA	NA
HHV of furnace ash; Btu/lb	NA	NA	NA	NA	NA
Combustion air flow; lb/h	14,657	14,694	14,935	15,031	14,555
Boiler draft; in H2O	-0.02	-0.03	-0.03	-0.04	-0.02
Boiler efficiency; %	83.88	84.79	85.04	84.32	86.07
Relative humidity, %	60	60	60	60	60
Mill air flow rate; lb/h	388;1,853	356;1,685	390	392;1,871	369;1,775
Mill outlet temperature; °F	197	201	220	188	230
Natural gas temperature; °F	73	91	87	85	79
EMISSIONS					
O2; %	3.5	3.6	3.8	3.5	3.5
CO; ppm;lb/MMBtu@3%O2	129;0.11	166;0.14	114;0.10	118;0.10	119;0.10
CO2; %	15.4	15.4	15.3	15.6	15.9
SO2; ppm;lb/MMBtu@3%O2	474;0.92	511;1.00	538;1.08	478;0.95	540;1.07
NOx; ppm;lb/MMBtu@3%O2	385;0.54	361;0.51	325;0.47	341;0.48	474;0.68
Particulates; gr/SCF	NM	NM	NM	NM	NM
ECONOMIC ANALYSIS DATA					
ID fan power consumption; w/h	NM	NM	NM	NM	NM
FD fan power consumption; w/h	NM	NM	NM	NM	NM
Pulverizer power consumption; w/h	NM	NM	NM	NM	NM
Booster fan power consumption; w/h	NM	NM	NM	NM	NM
Ash collection power consumption; w/h	NA	NA	NA	NA	NA
Crusher power consumption; w/h	NA	NA	NA	NA	NA
Reddler conveyor power consumption; w/h	NA	NA	NA	NA	NA
Feed screw power consumption; w/h	NA	NA	NA	NA	NA
Feedwater pump power comsumption; w/h	NM	NM	NM	NM	NM
Total air usage; scfm (Pilot burner)	NM	NM	NM	NM	NM
Maximum load (based on 14,700 lb steam/h); %	95.5	94.8	96.2	92.5	89.3

Table 4. Coal Analysis

Date	Weigh Belt Composite	Full Proximate Analysis				Ultimate Analysis					Cal Value (Dry)
		% Moist	% V.M. (Dry)	% Ash (Dry)	% F.C. (Dry)	% C (Dry)	% H (Dry)	% N (Dry)	% S (Dry)	% O (Dry)	
24Jul95-28Jul95		2.38 ± 0.04	31.48 ± 0.06	6.97 ± 0.03	61.55	79.51 ± 0.16	5.18 ± 0.02	1.55 ± 0.01	0.59 ± 0.01	6.19	13926 ± 10
31Jul95-04Aug95		2.19 ± 0.01	31.54 ± 0.05	6.64 ± 0.01	61.82	79.75 ± 0.02	5.21 ± 0.01	1.53 ± 0.00	0.60 ± 0.01	6.27	13970 ± 13
07Aug95-11Aug95		1.99 ± 0.04	31.32 ± 0.05	4.57 ± 0.03	64.11	82.32 ± 0.21	5.29 ± 0.01	1.41 ± 0.00	0.77 ± 0.01	5.64	14414 ± 7
21Aug95-25Aug95		1.87 ± 0.01	30.82 ± 0.02	4.36 ± 0.01	64.82	82.41 ± 0.19	5.04 ± 0.01	1.40 ± 0.00	0.81 ± 0.02	5.98	14444 ± 2
28Aug95-01Sep95		1.79 ± 0.01	30.94 ± 0.06	4.31 ± 0.02	64.75	82.78 ± 0.01	5.16 ± 0.02	1.41 ± 0.02	0.85 ± 0.01	5.49	14490 ± 10
04Sep95-08Sep95		2.40 ± 0.03	30.80 ± 0.17	4.34 ± 0.03	64.86	82.05 ± 0.74	5.21 ± 0.07	1.41 ± 0.00	0.84 ± 0.01	6.15	14533 ± 12

Coal samples are collected on a daily basis from the weigh-belt feeder outlet and weekly composites are made. Upper Freeport seam coal was tested from 07/24/95 through 08/04/95. Middle Kittanning seam coal was tested from 08/07/95 through 09/08/95.

Table 5. Coal Particle Size Distribution for Samples Isokinetically Collected at the Burner Inlet

Test Date	Test Time	Mill Speed (rpm)	Mill Amps	Mill Air Flow (cfm)	Coal Feed Rate (lb/m)	Mill Temp. (F) Air Inlet	Mill Temp. (F) Mill Outlet	Top Size	Particle Size, In Microns, that Is Less Than the Indicated Size <99	<95	<90	<75	<50	<10
8/9/95	1050	1940	N.M.	352	19.0	88.4	226.9	188	160	80.8	63.3	36.4	21.5	5.4
8/9/95	1125	1,940	N.M.	351	19.0	89.5	226.7	188	129	84.5	65.5	38.0	21.4	5.4
8/9/95	1445	1940	N.M.	320	19.0	97.4	246.3	188	141	73.1	59.3	34.8	19.8	5.0
8/23/95	1600	1,940	N.M.	341	19.0	83.8	214.9	188	143	75.0	60.6	35.7	20.3	6.1
8/24/95	1130	1940	N.M.	372	19.0	80.4	202.8	188	149	77.7	62.5	37.1	20.9	5.3
8/24/95	1600	1,940	N.M.	361	19.0	84.3	200.3	188	129	83.2	64.0	37.7	20.9	5.8
8/30/95	1220	1940	N.M.	386	19.0	92.0	198.0	188	165	99.0	70.2	42.6	23.2	5.8
8/31/95	1310	1,940	N.M.	390	19.0	85.6	190.7	188	144	75.4	62.3	37.4	21.0	5.2
9/5/95	1315	2080	88	367	18.3	86.0	255.9	188	122	76.2	53.8	30.1	17.1	4.5
9/5/95	1440	2,080	87	386	18.3	80.9	246.8	188	116	73.6	64.6	32.1	18.2	4.8
9/6/95	1345	2080	85	374	18.3	87.3	239.7	163	100	67.2	49.7	29.0	16.9	4.7
9/7/95	1020	2,080	83	393	17.7	80.8	222.0	163	109	74.1	56.5	33.0	19.4	5.2

Table 6. Mill Performance Comparison

Coal Seam:	Brookville	Kentucky	Middle Kittanning	Middle Kittanning
Operating Conditions				
Mill air flow; acfm	370-400	370-400	320-390	365-395
Coal flow; lb/m	16.5-18.5	16.5-18.5	19.0	18.3-19.0
Mill speed; rpm	1,940	1,940	1,940	2,080
Particle Size (μm)				
Top size	190-300	250-275	190	160-190
D_{80}	50-70	50-70	45-50	35-40
D_{50}	25-30	25-30	20-22	17-19

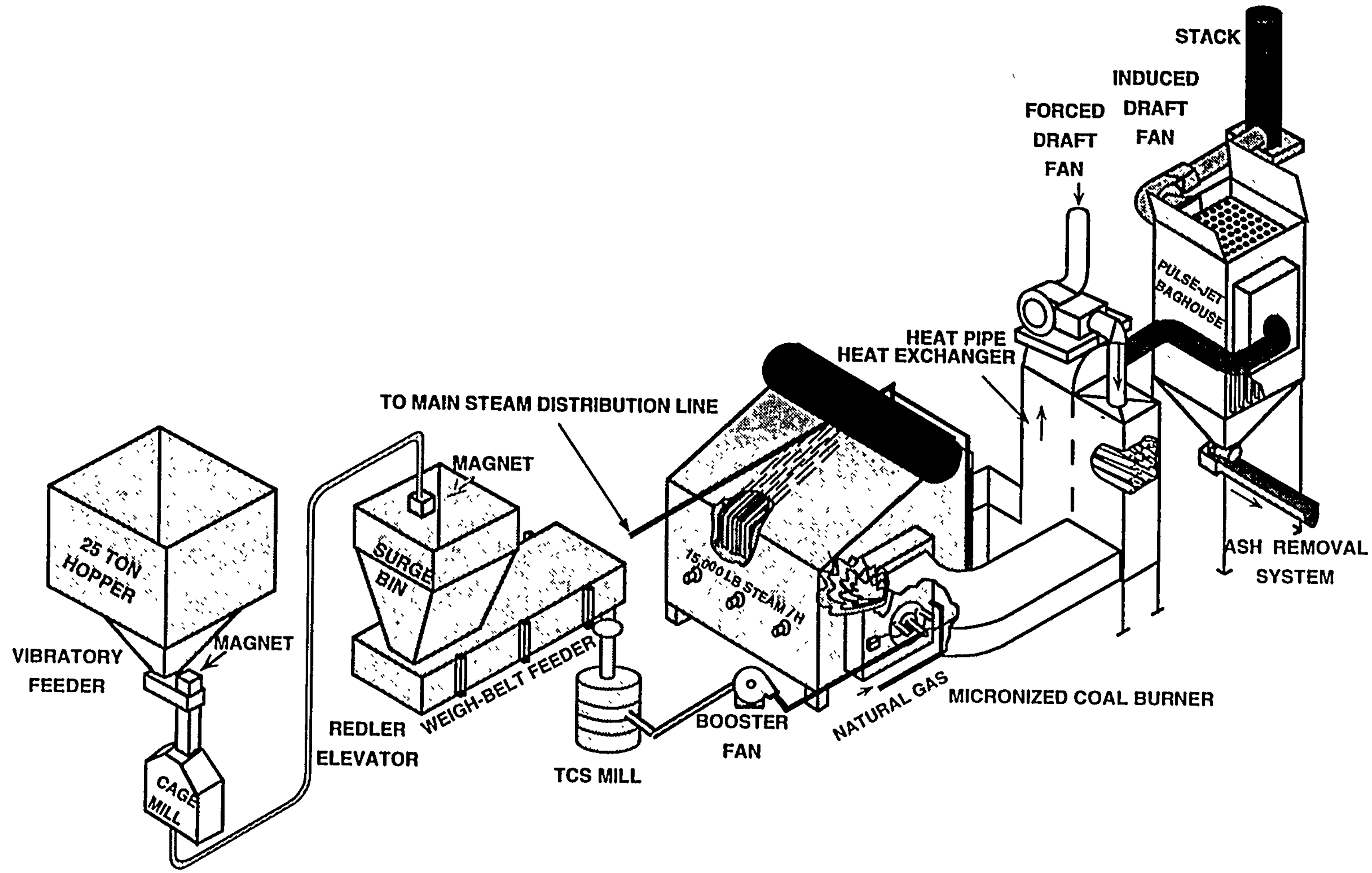


Figure 1. MICRONIZED COAL-FIRED BOILER SYSTEM WITH COAL HANDLING MODIFICATIONS

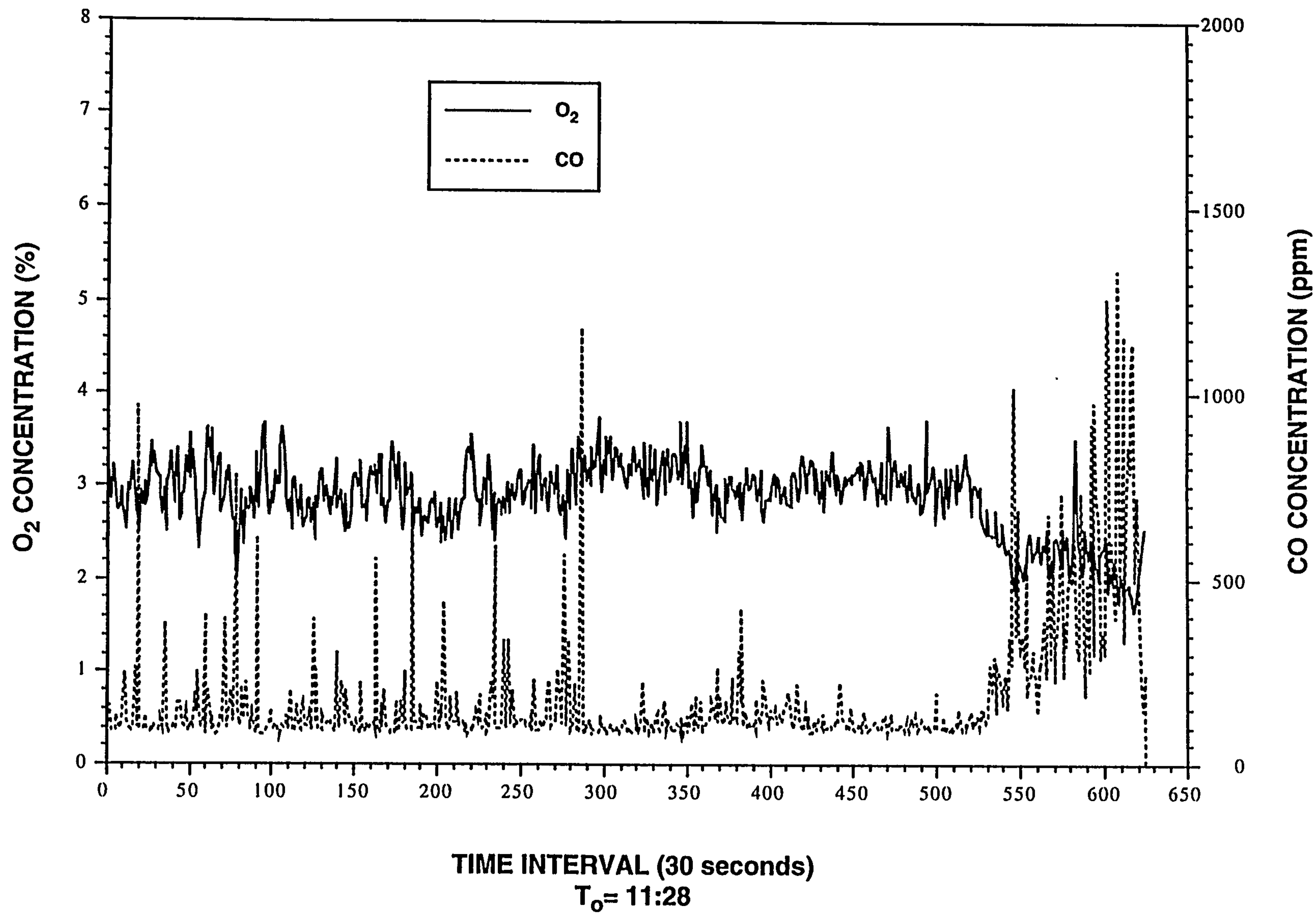


Figure 2. O_2 AND CO CONCENTRATION vs. TIME FOR TESTING CONDUCTED ON 12/07/93

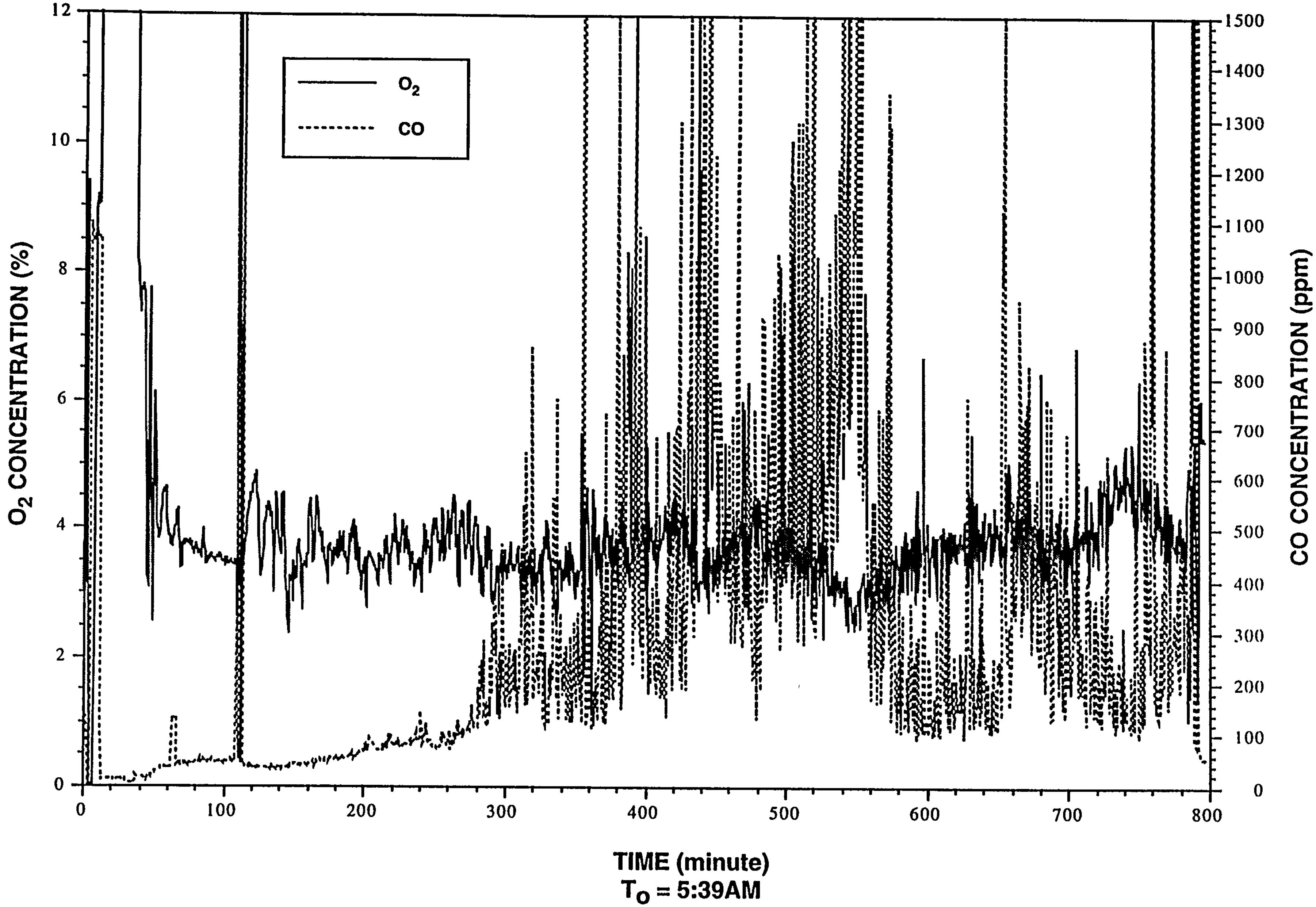


Figure 3. O_2 AND CO CONCENTRATION vs. TIME FOR TESTING CONDUCTED ON 04/28/94

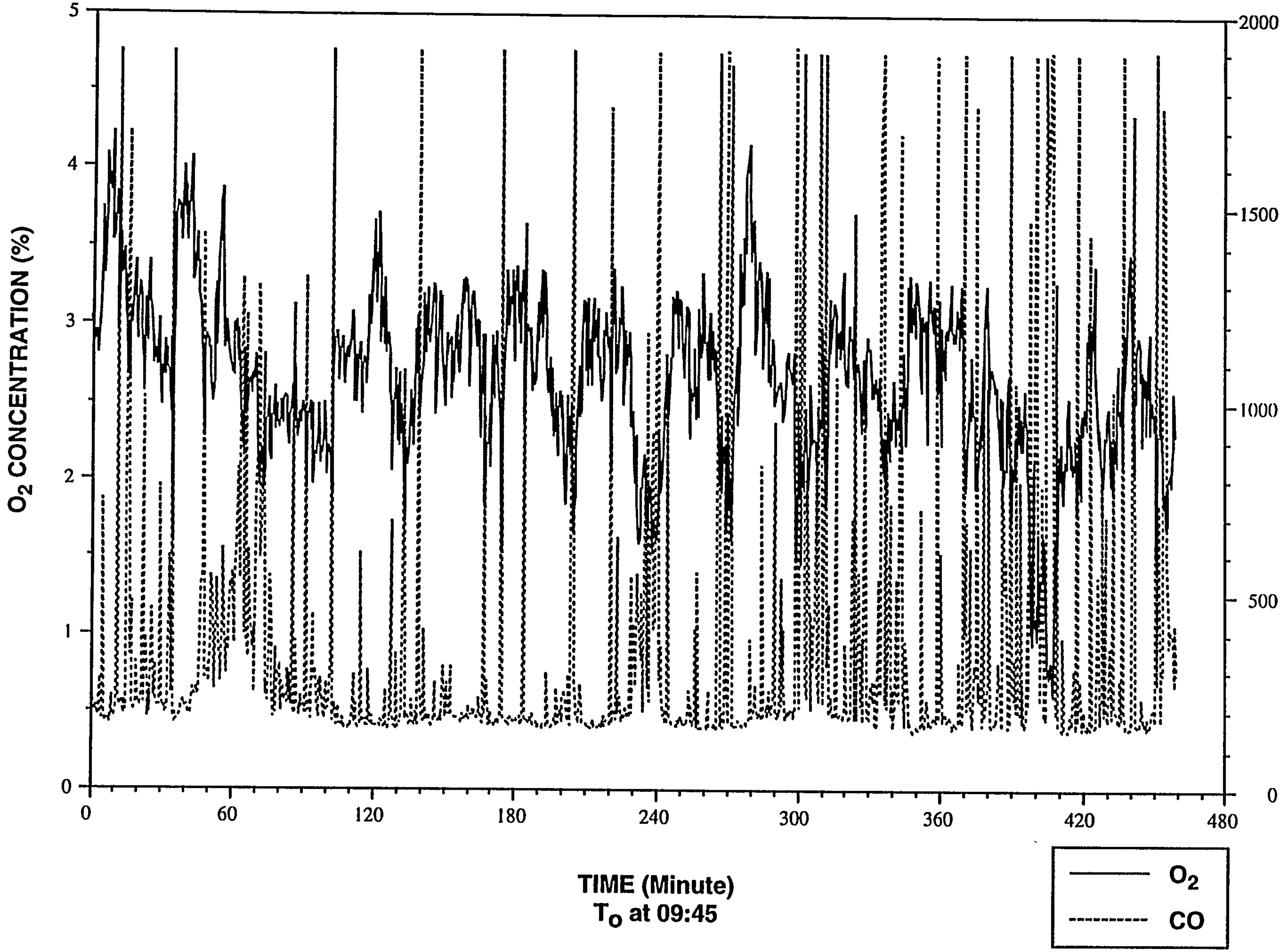


Figure 4. O_2 AND CO CONCENTRATION v. TIME FOR TESTING CONDUCTED ON 08/03/95

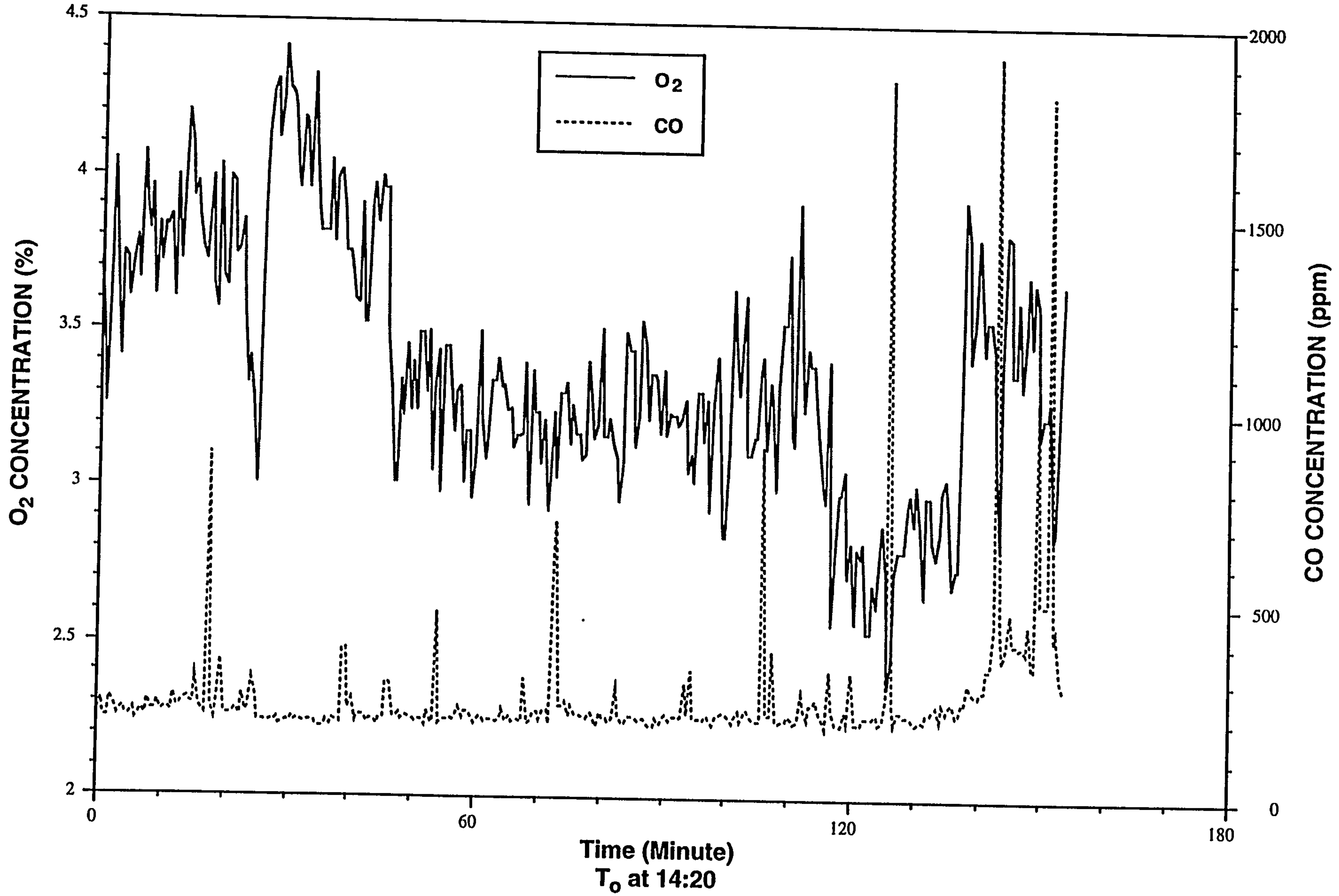


Figure 5. O_2 AND CO CONCENTRATION vs. TIME FOR TESTING CONDUCTED ON 08/23/95

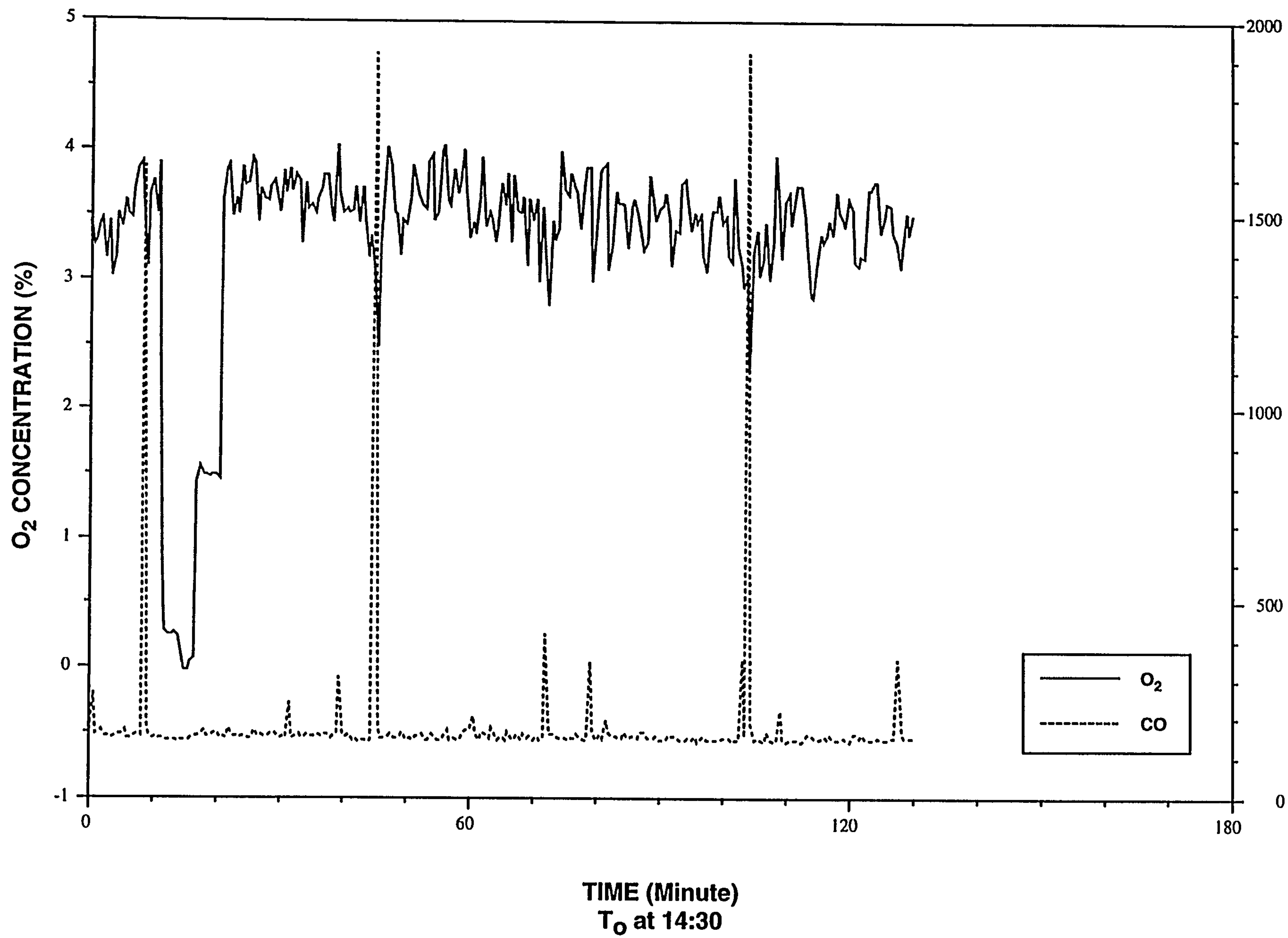


Figure 6. O_2 AND CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/25/95

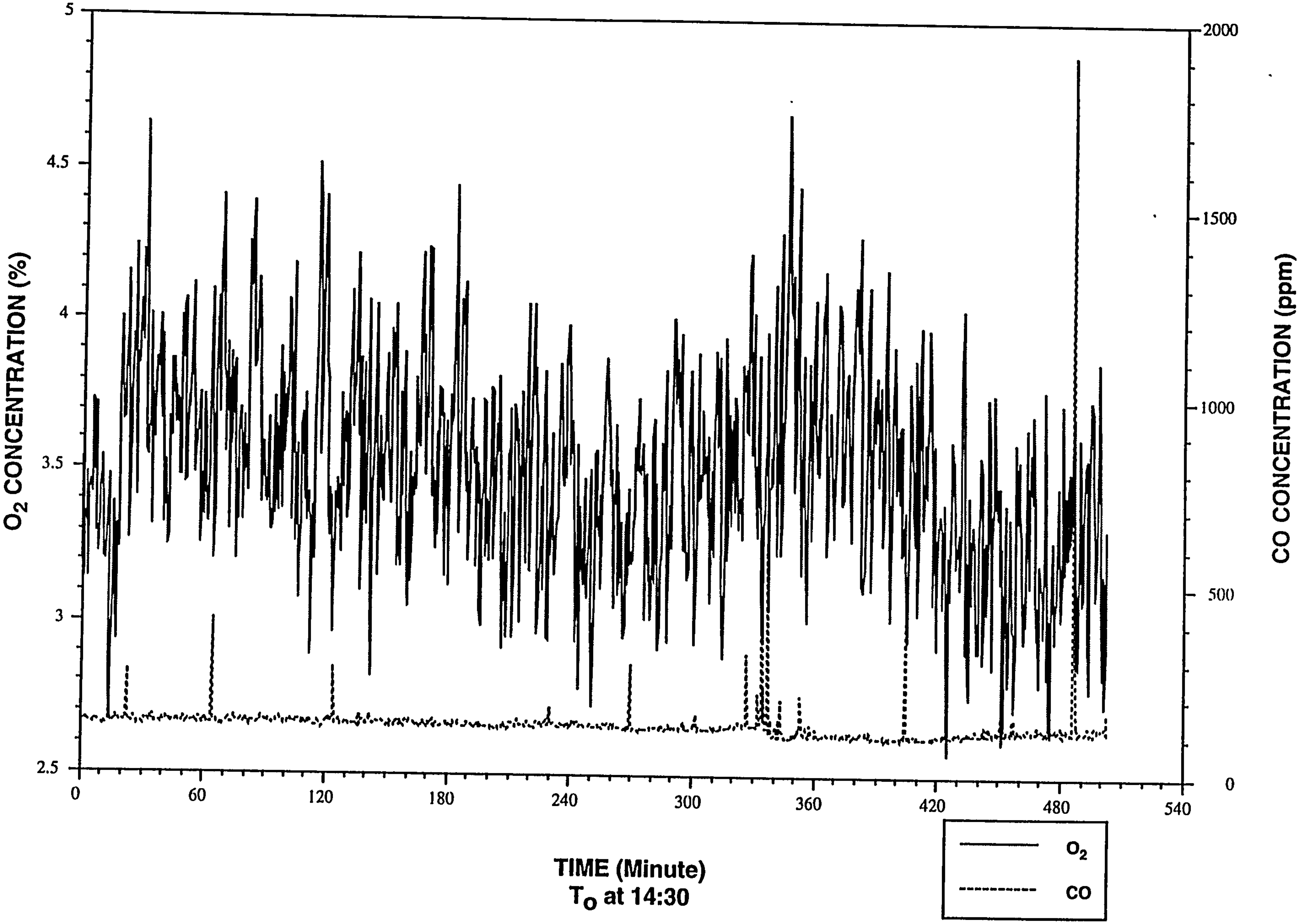


Figure 7. O_2 AND CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/28/95

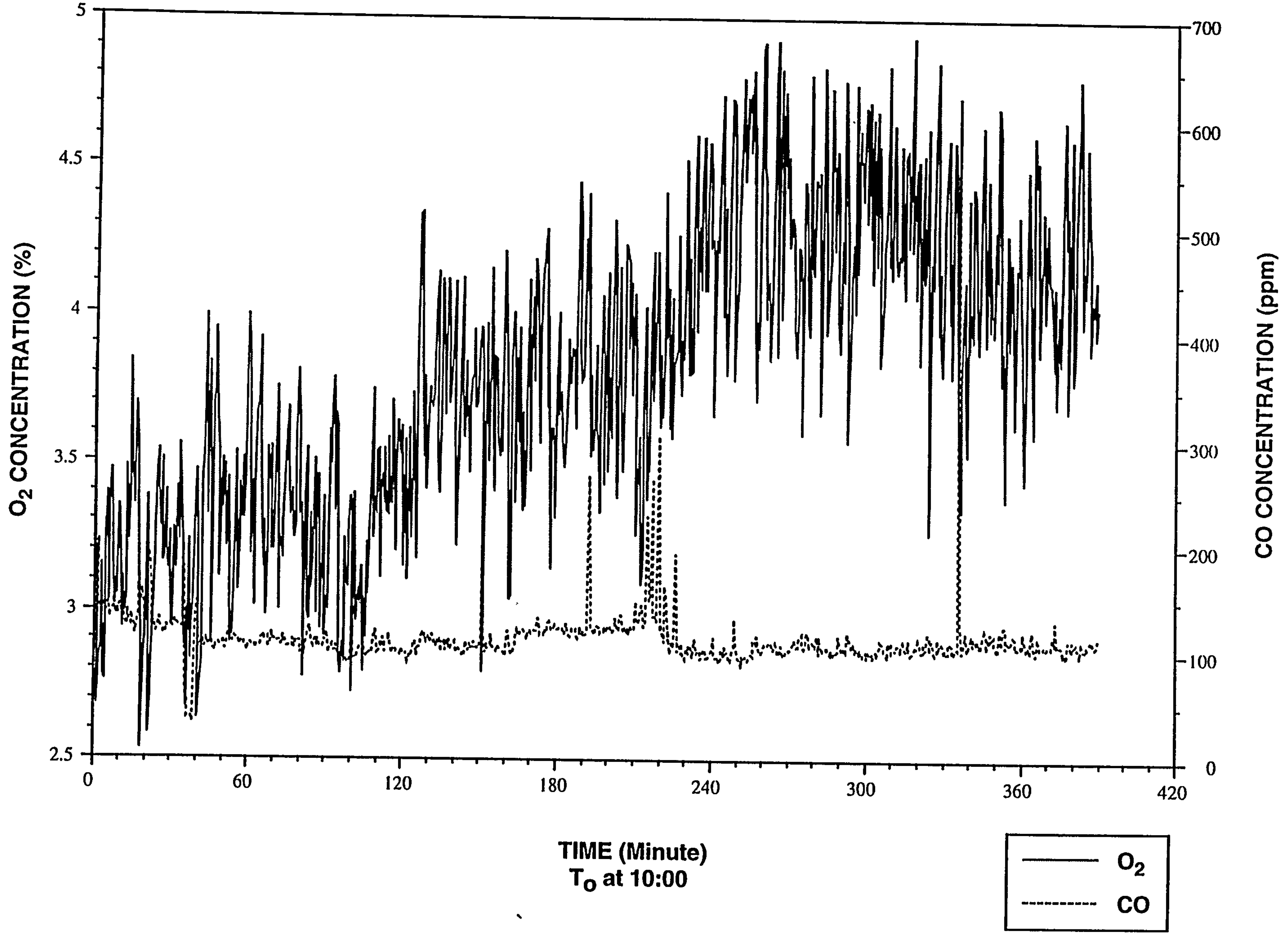


Figure 8. O_2 and CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/30/95

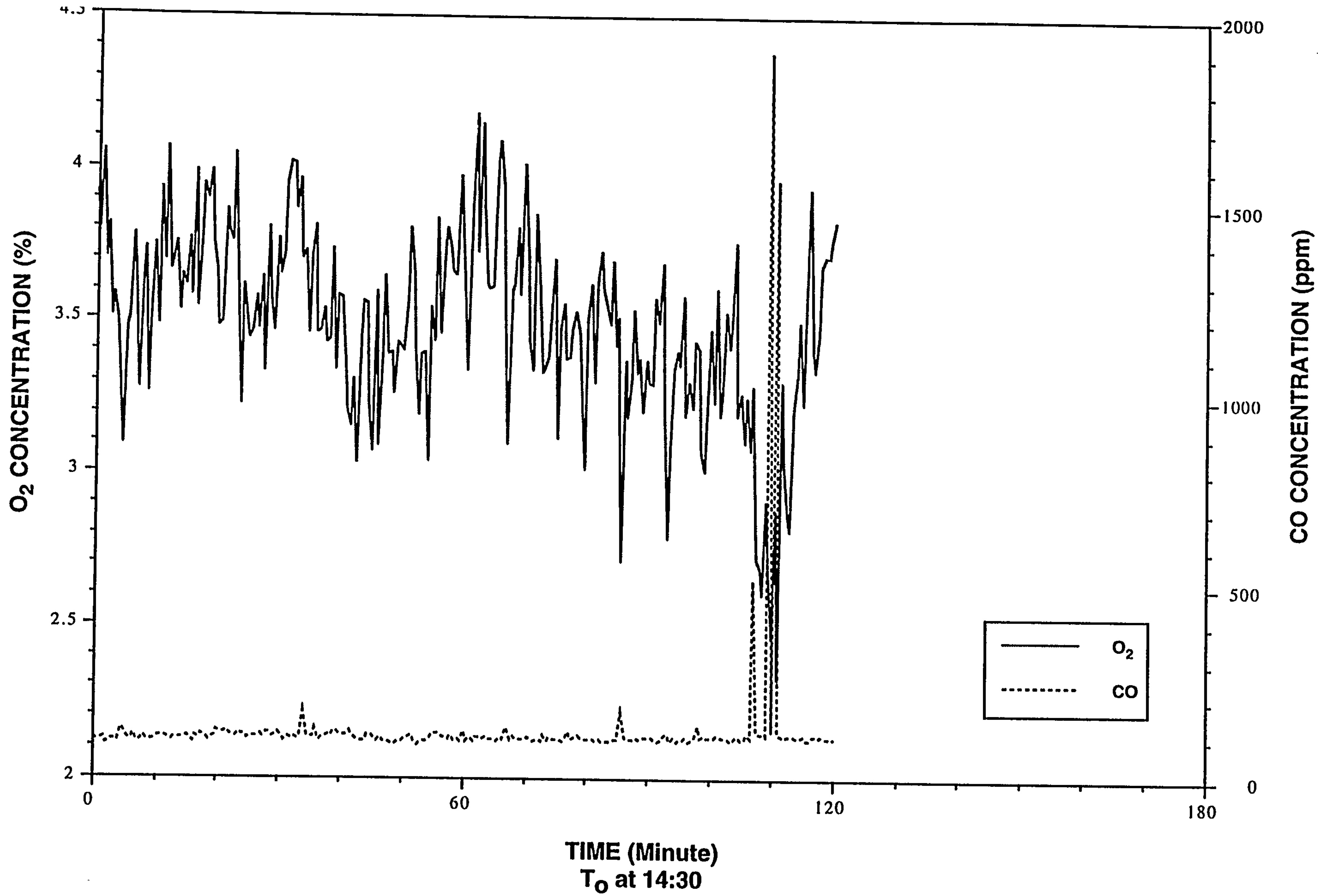


Figure 9. O_2 AND CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 09/05/95

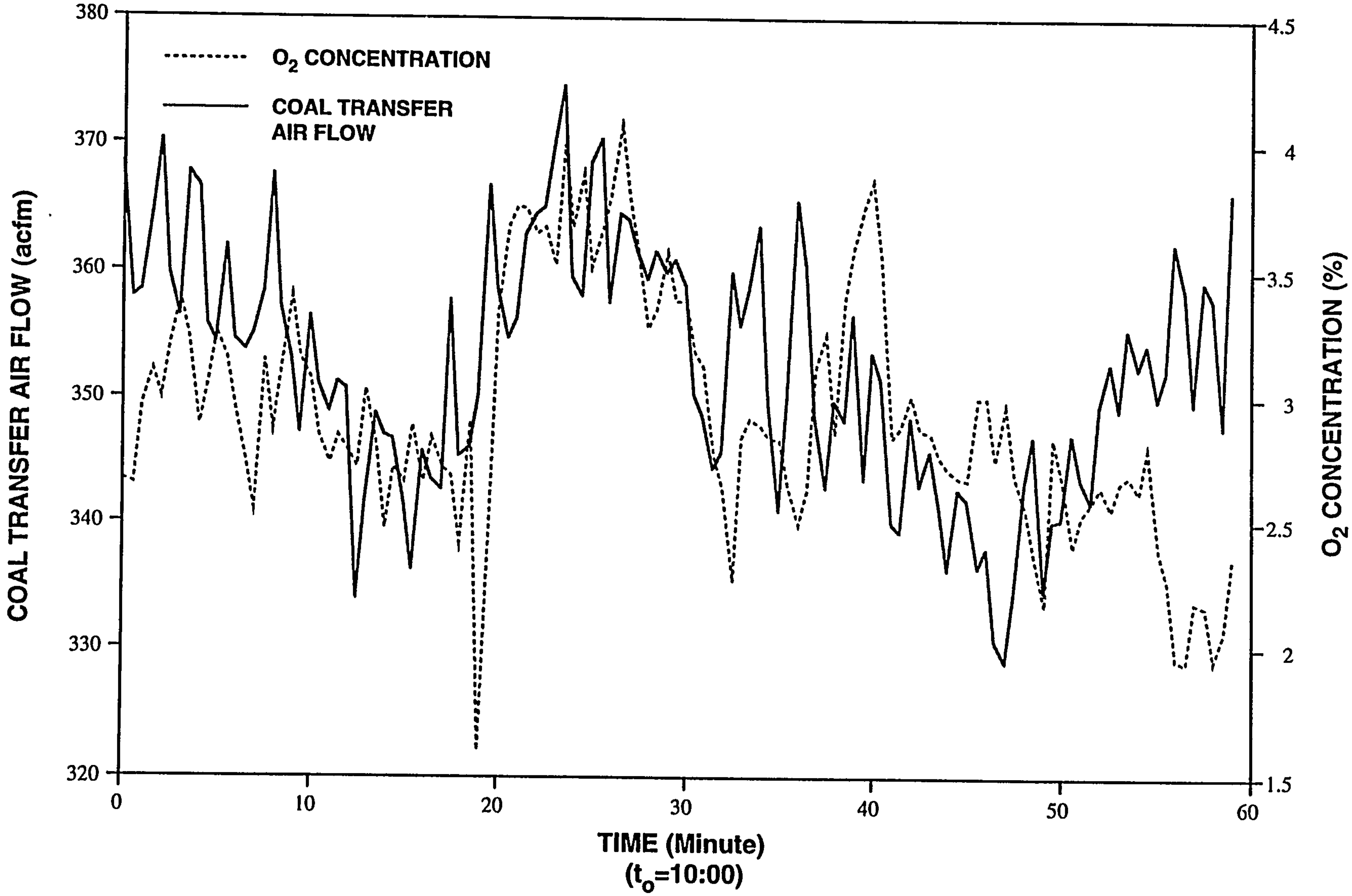


Figure 10. COAL TRANSFER AIR FLOW AND OXYGEN CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/03/95

0873

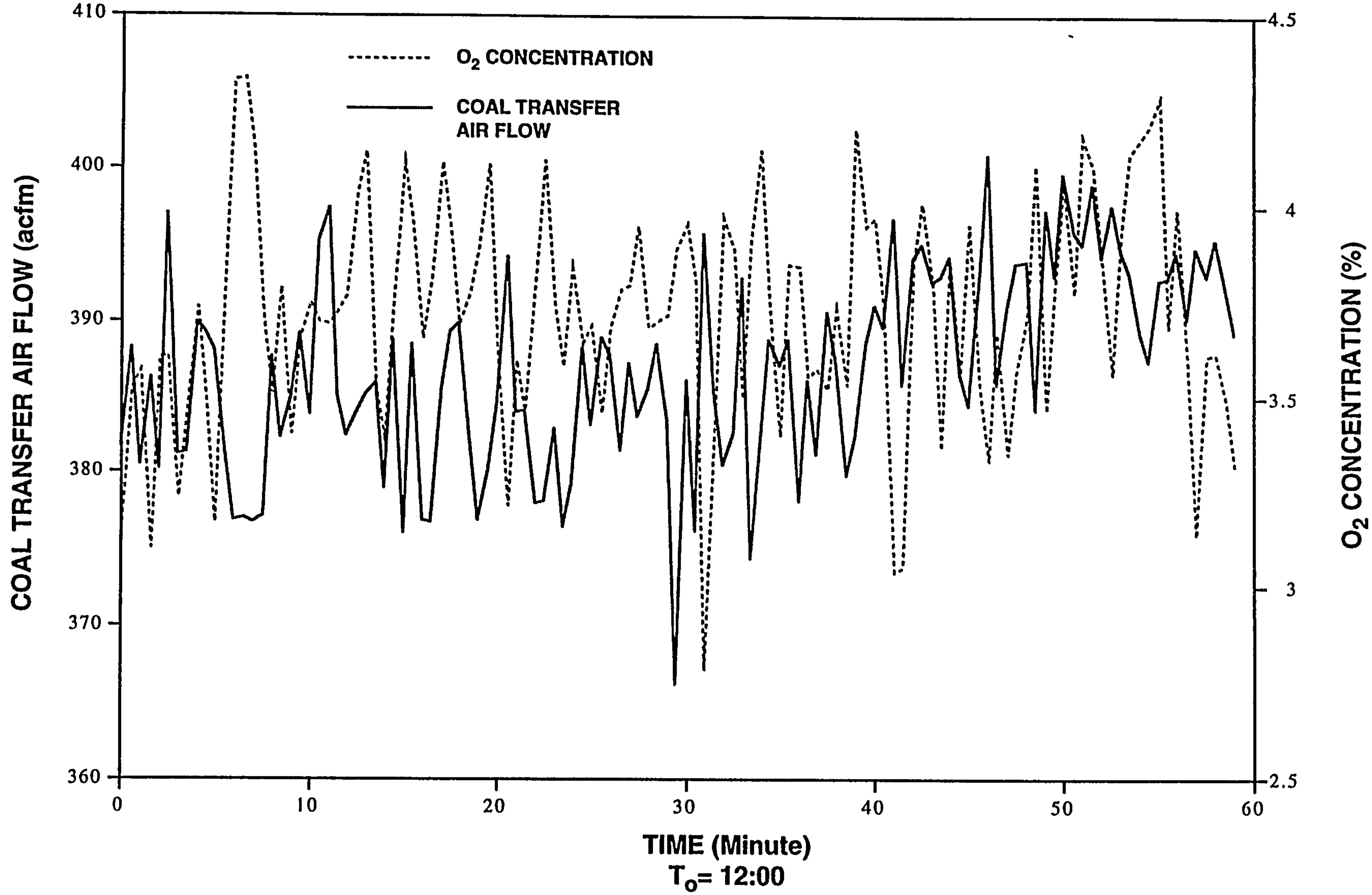


Figure 11. COAL TRANSFER AIR FLOW AND OXYGEN CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/30/95

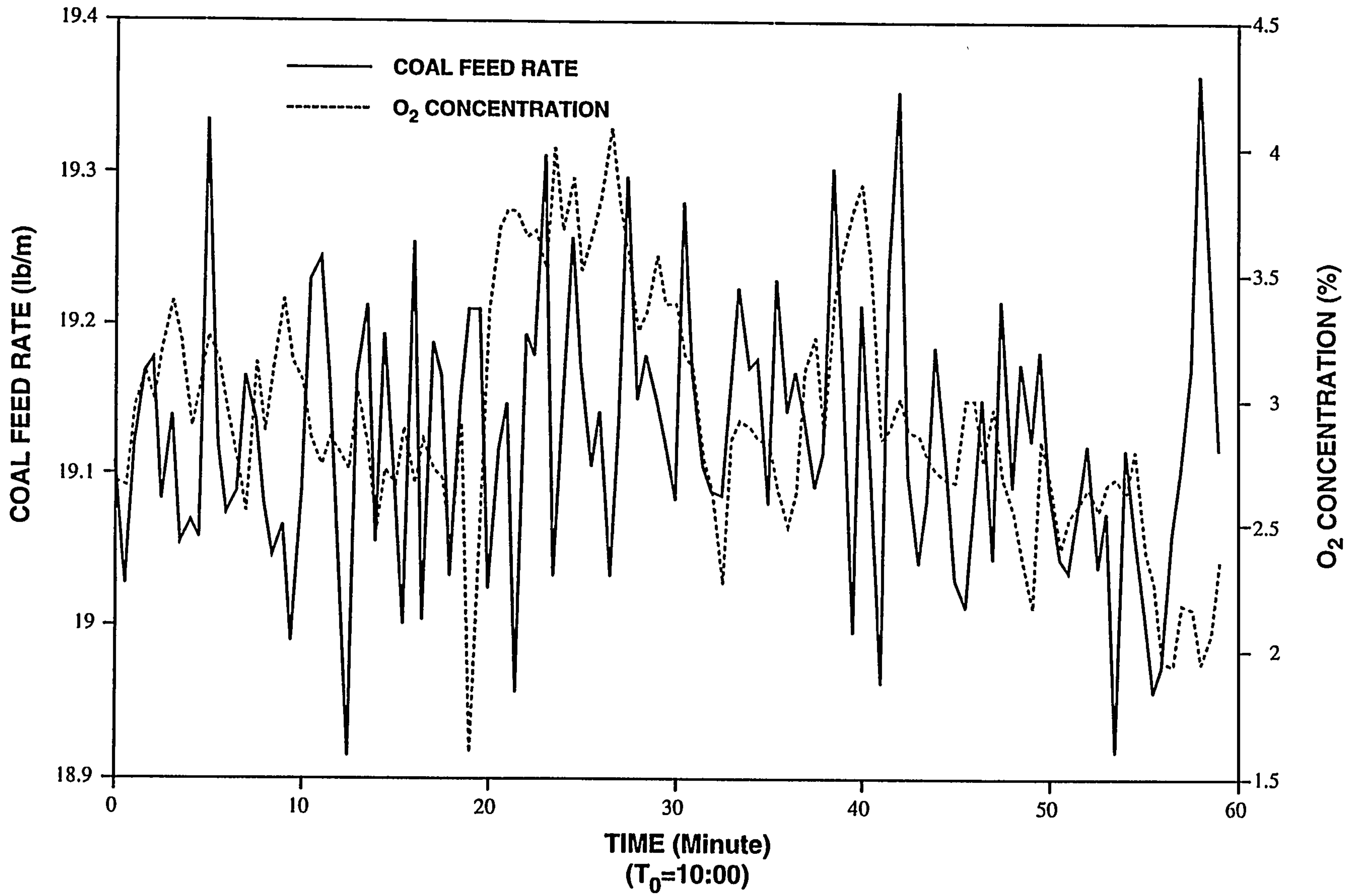


Figure 12. COAL FEED RATE AND OXYGEN CONCENTRATION vs TIME FOR THE TESTING CONDUCTED ON 08/03/95

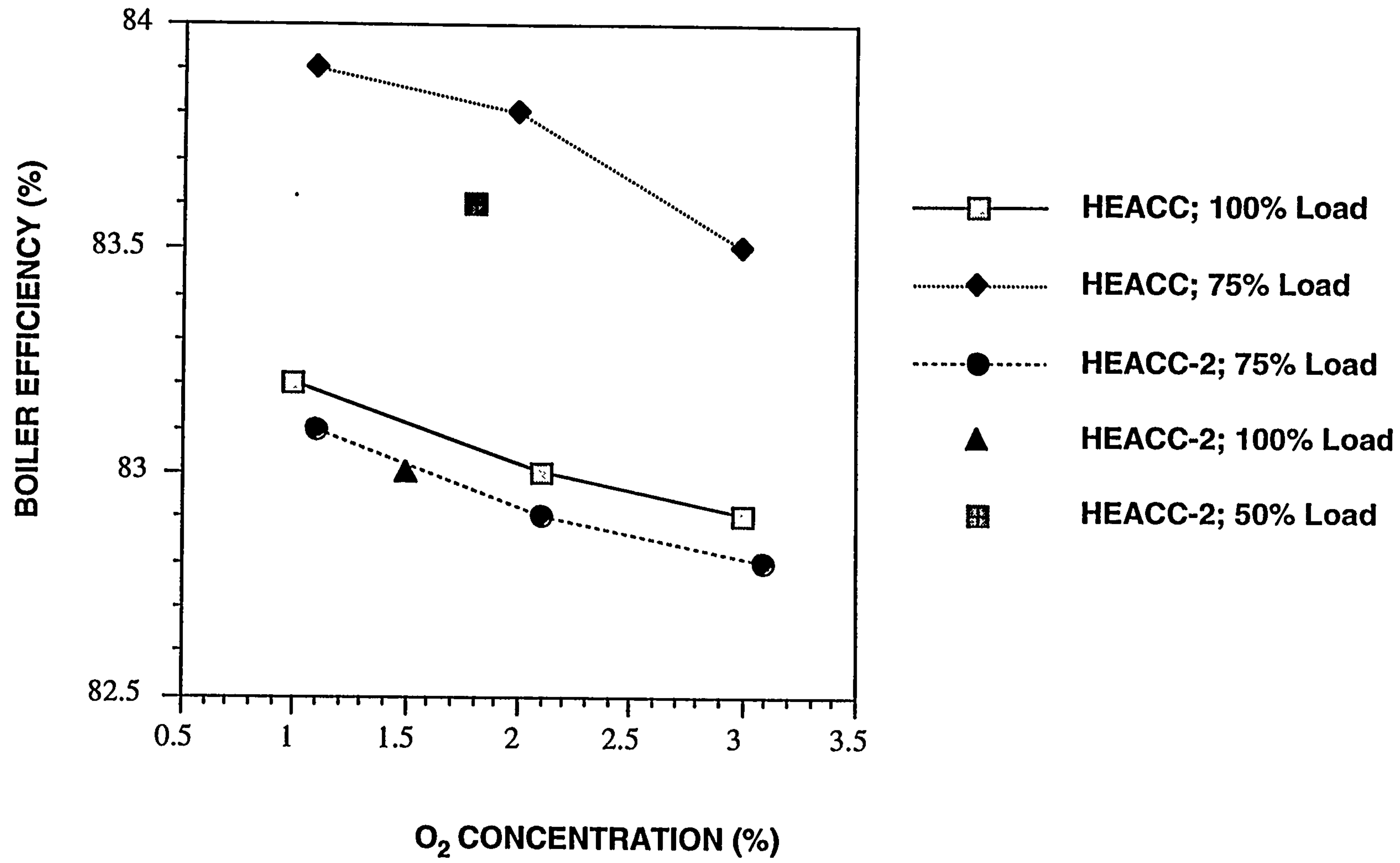
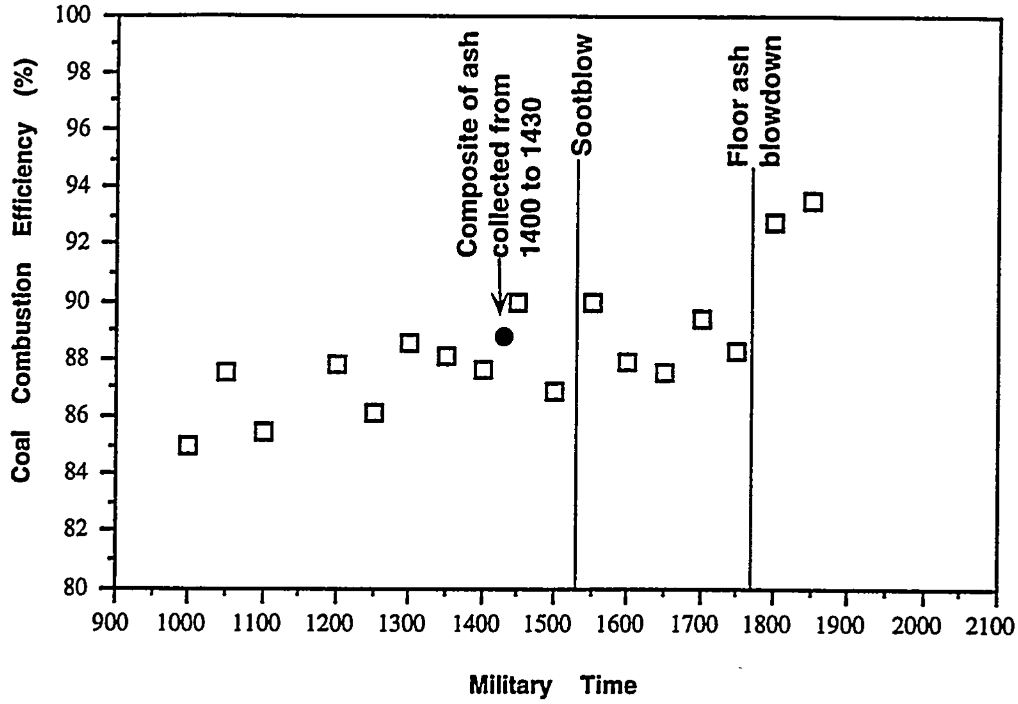
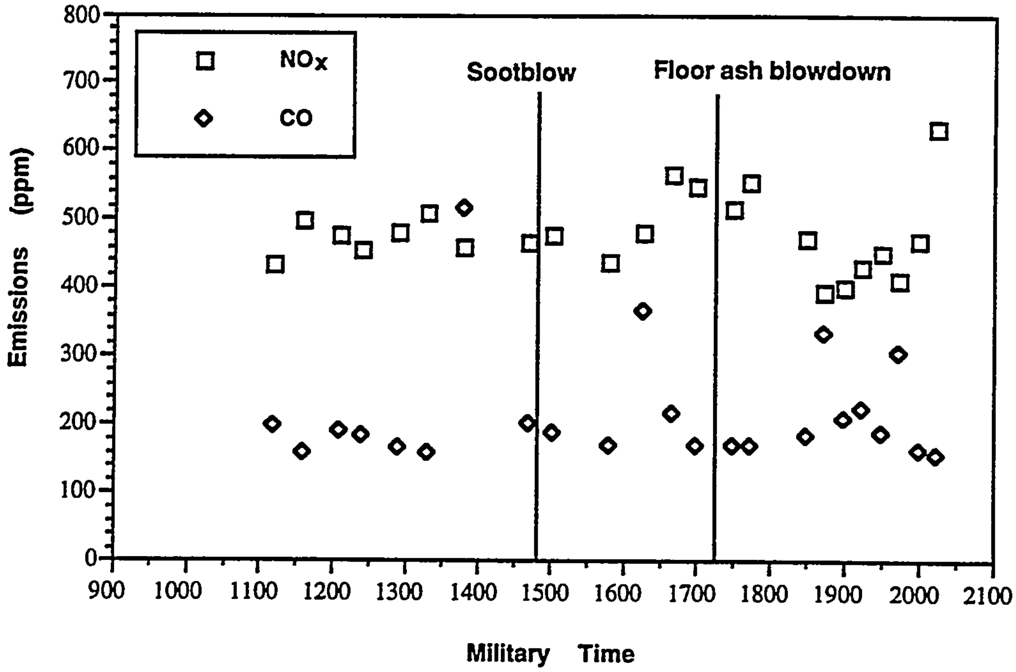


Figure 13. BOILER EFFICIENCY AS A FUNCTION OF O_2 CONCENTRATION FOR THE HEACC AND HEACC-2

0875



(a)



(b)

Figure 14. COAL COMBUSTION EFFICIENCY BASED ON THE BAGHOUSE ASH SAMPLES (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING CONDUCTED ON 08/03/95

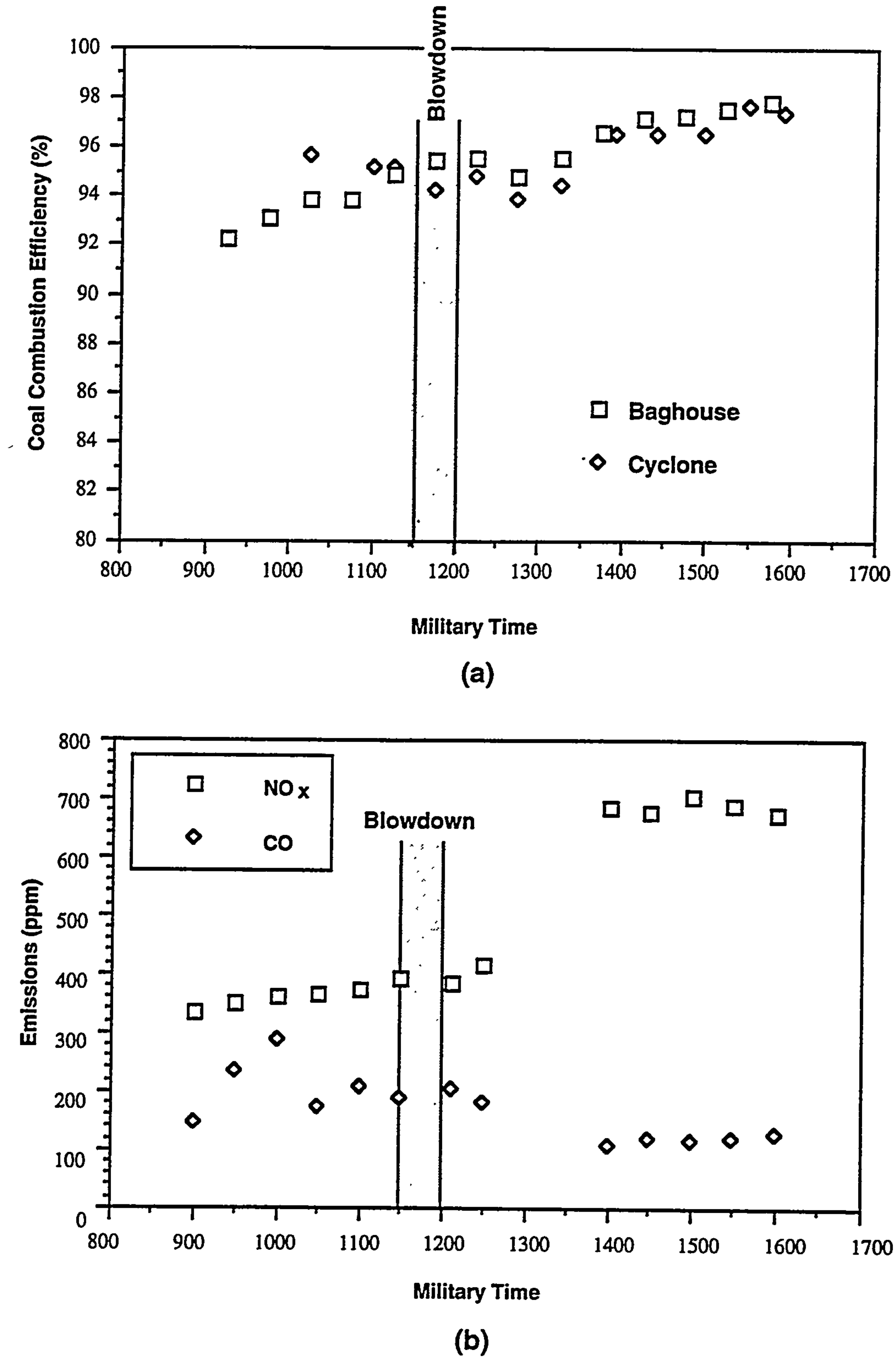


Figure 15. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/09/95

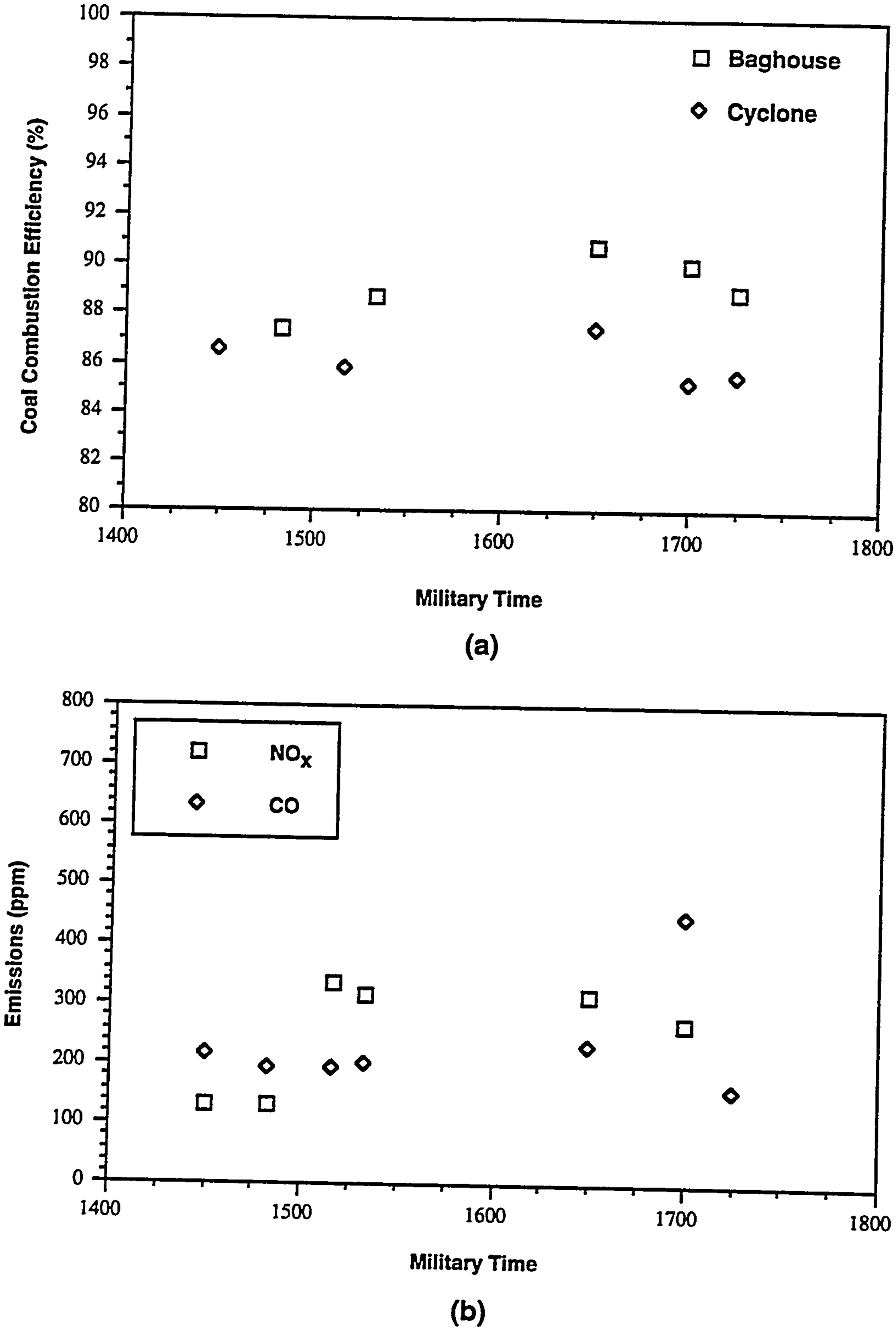


Figure 16. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/23/95

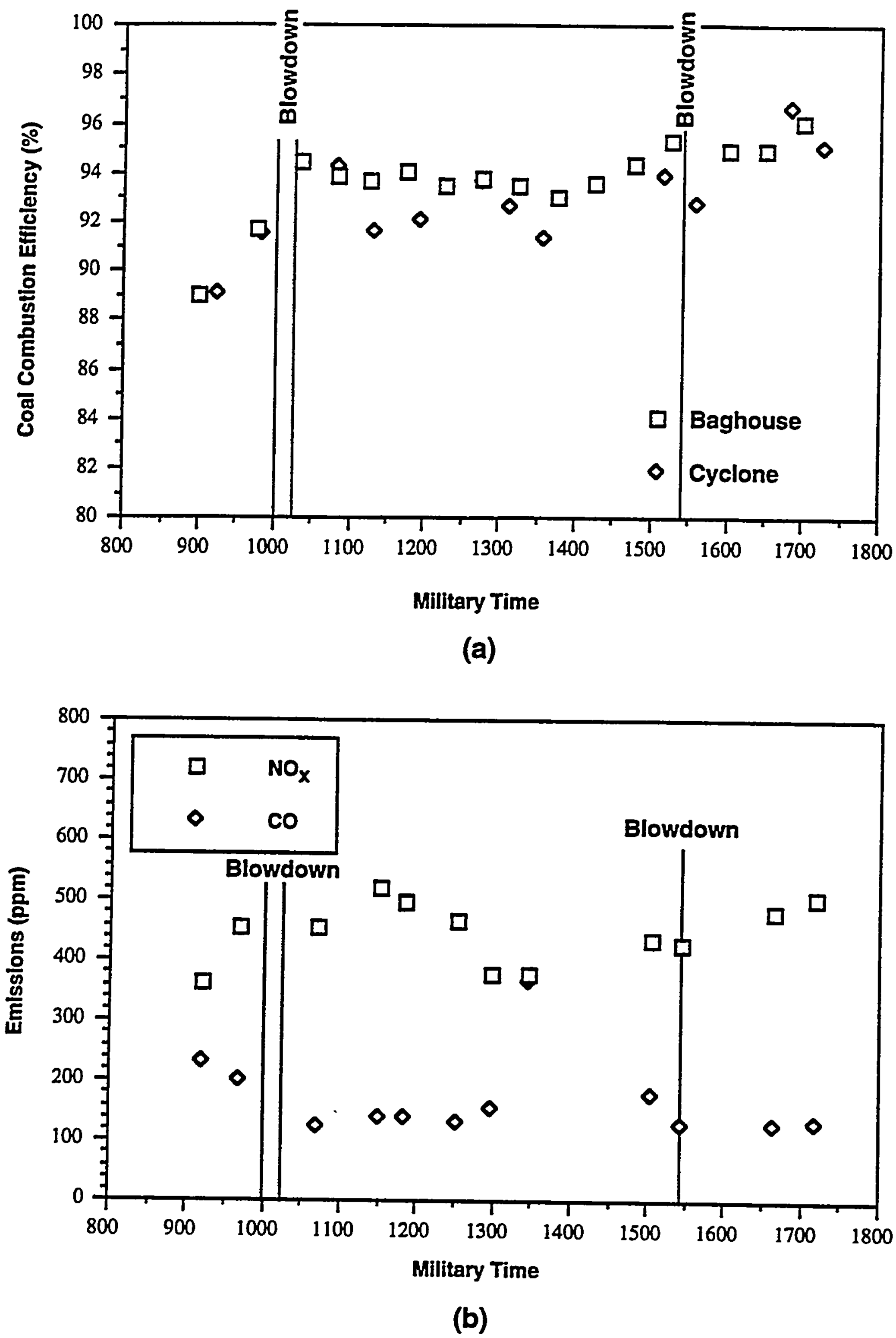
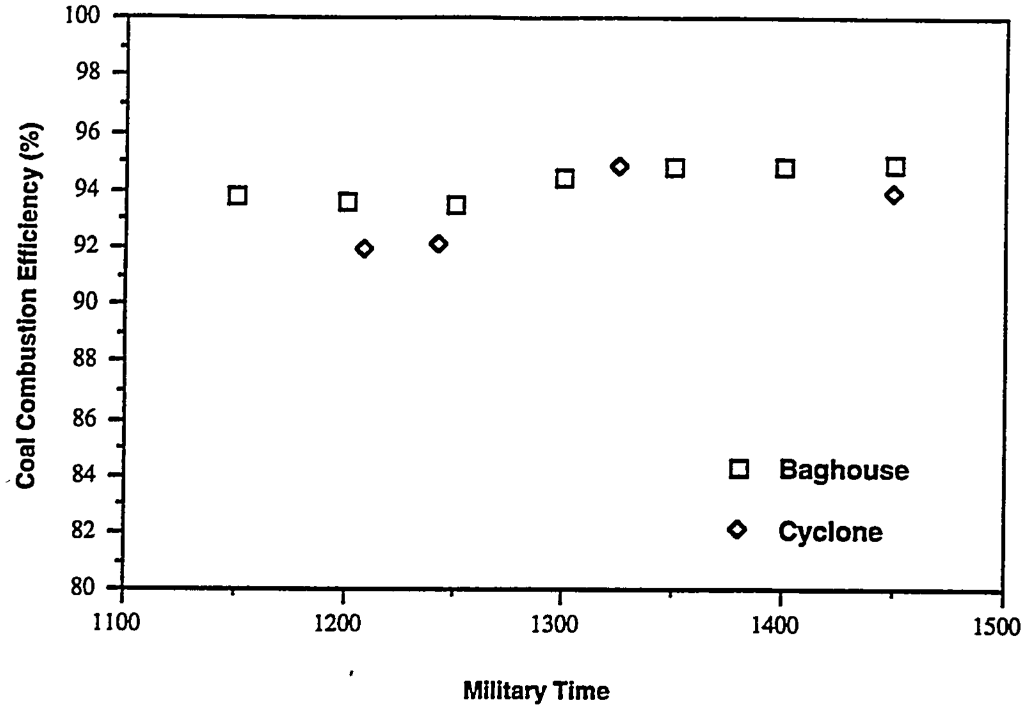
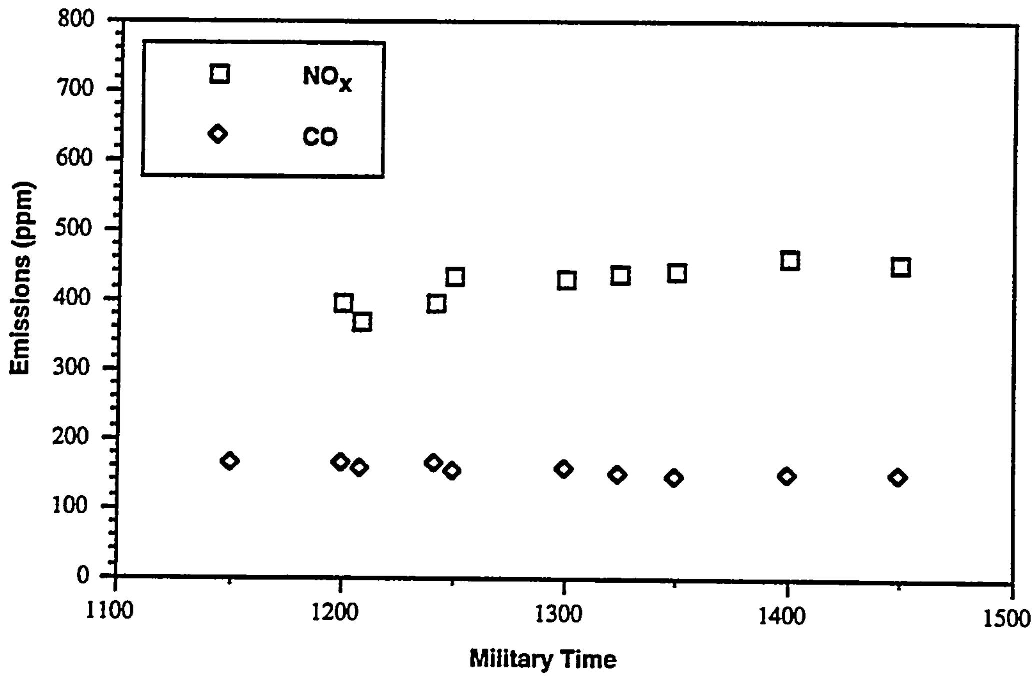


Figure 17. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/24/95

0660



(a)



(b)

Figure 18. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/25/95

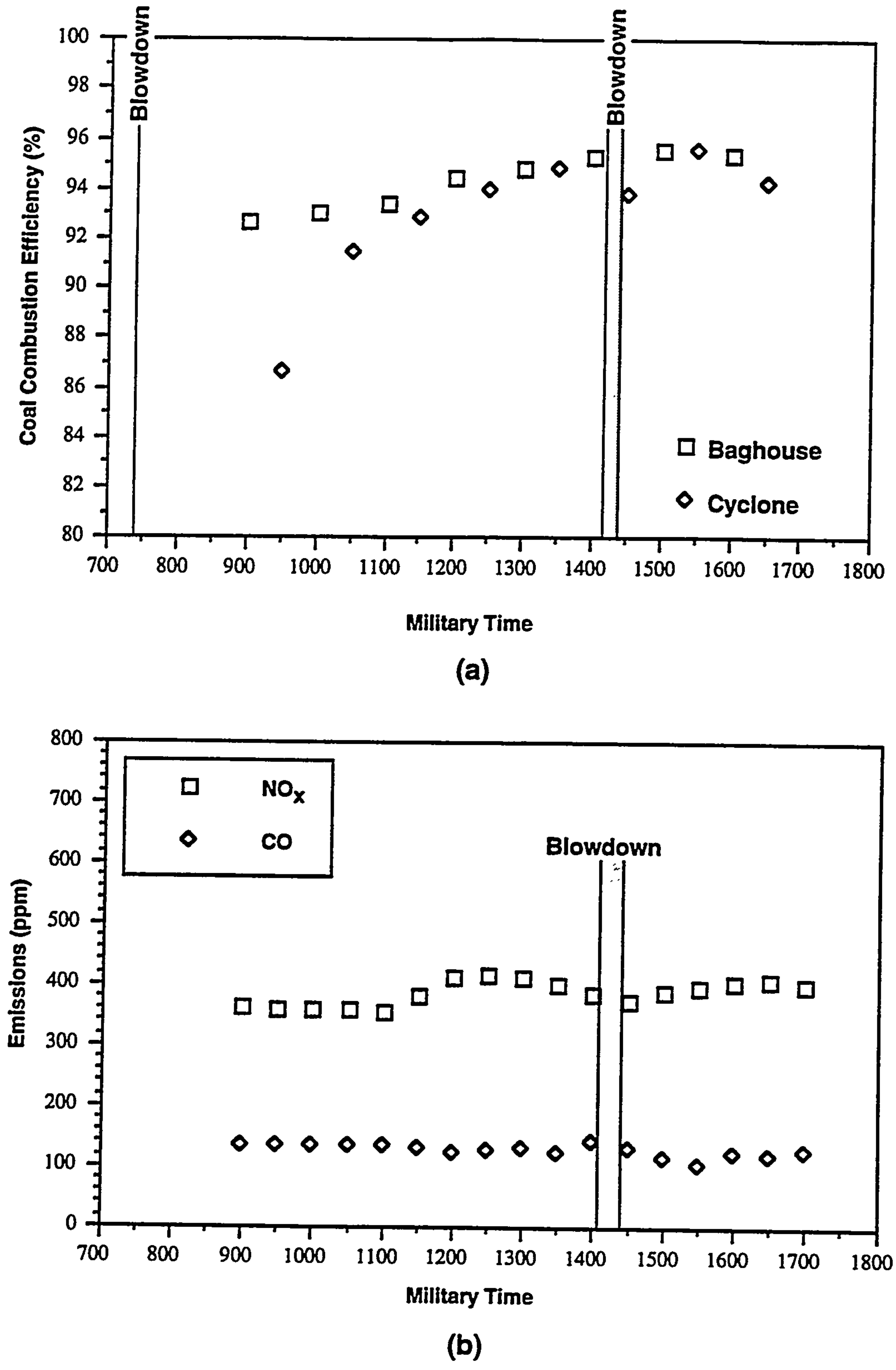


Figure 19. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/28/95

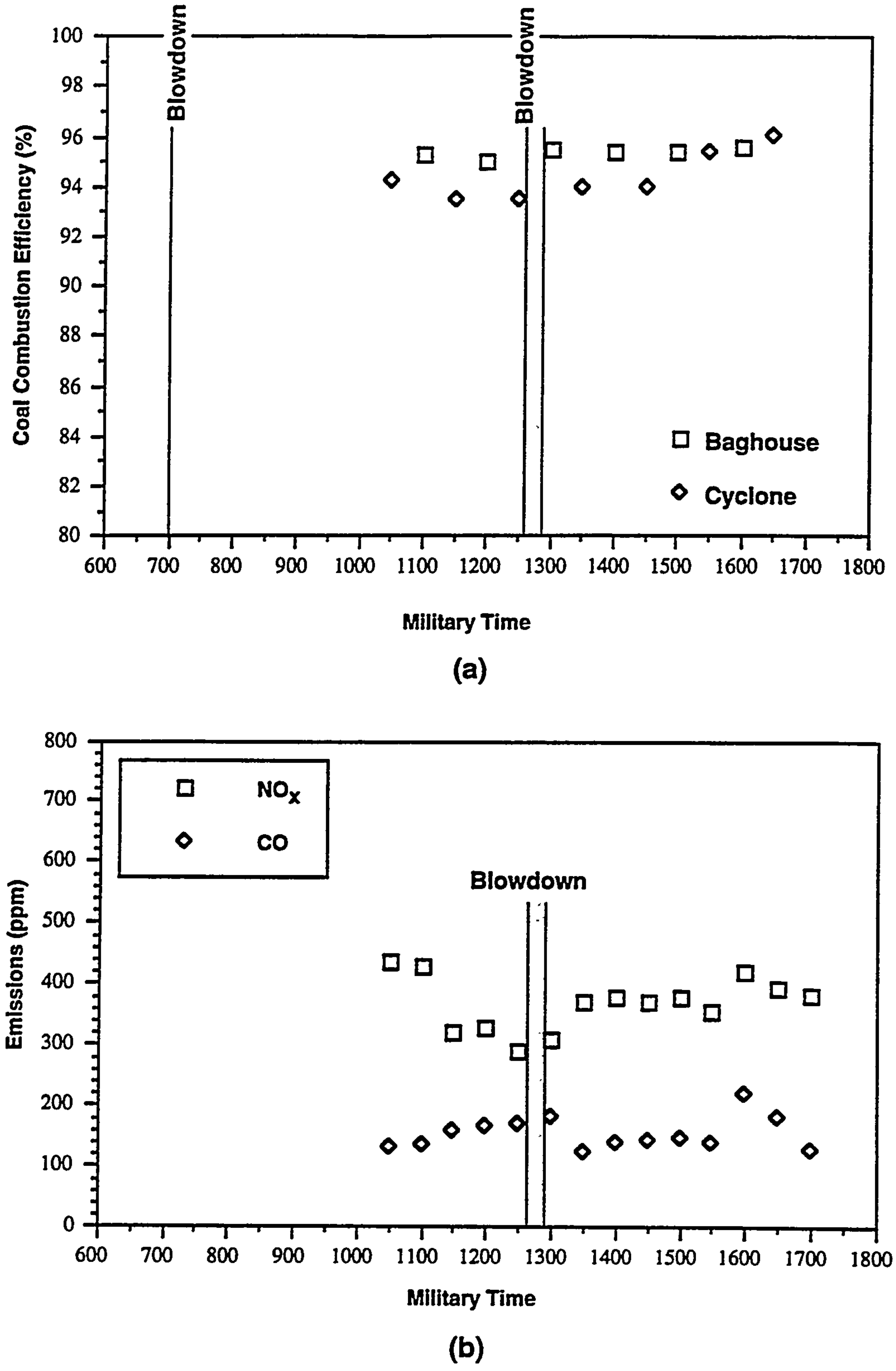
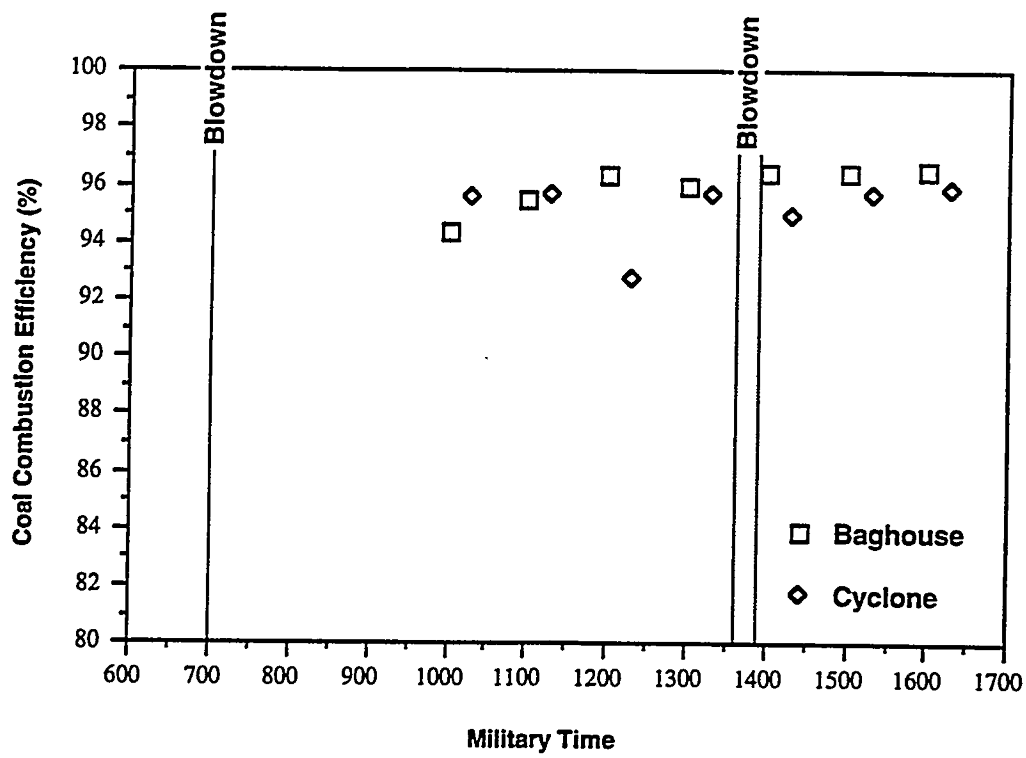
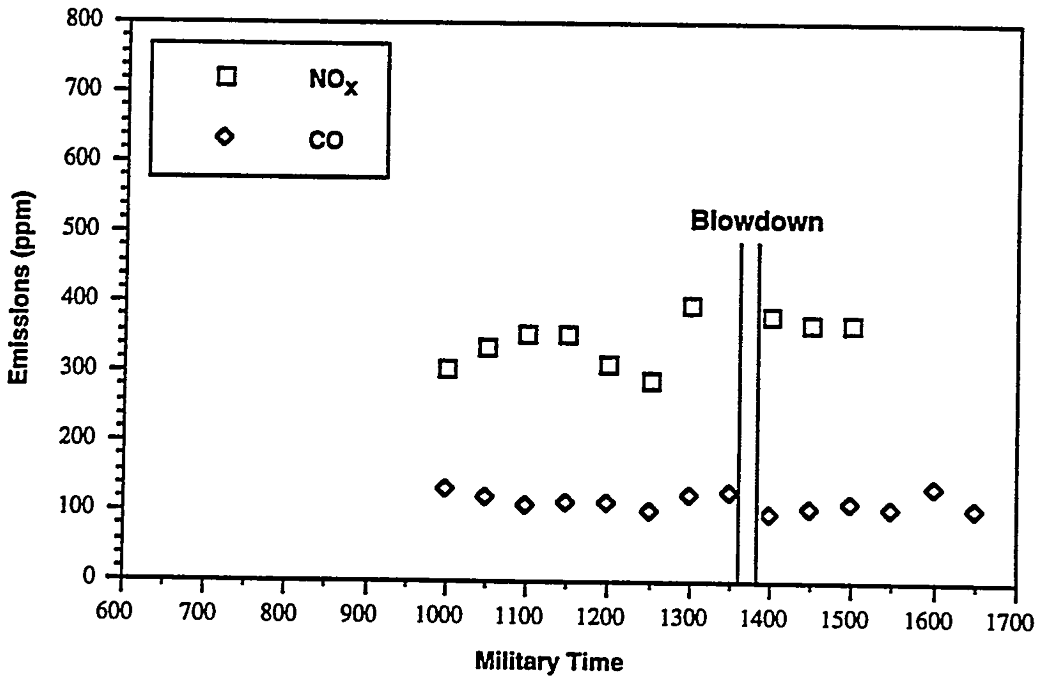


Figure 20. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/29/95

0863



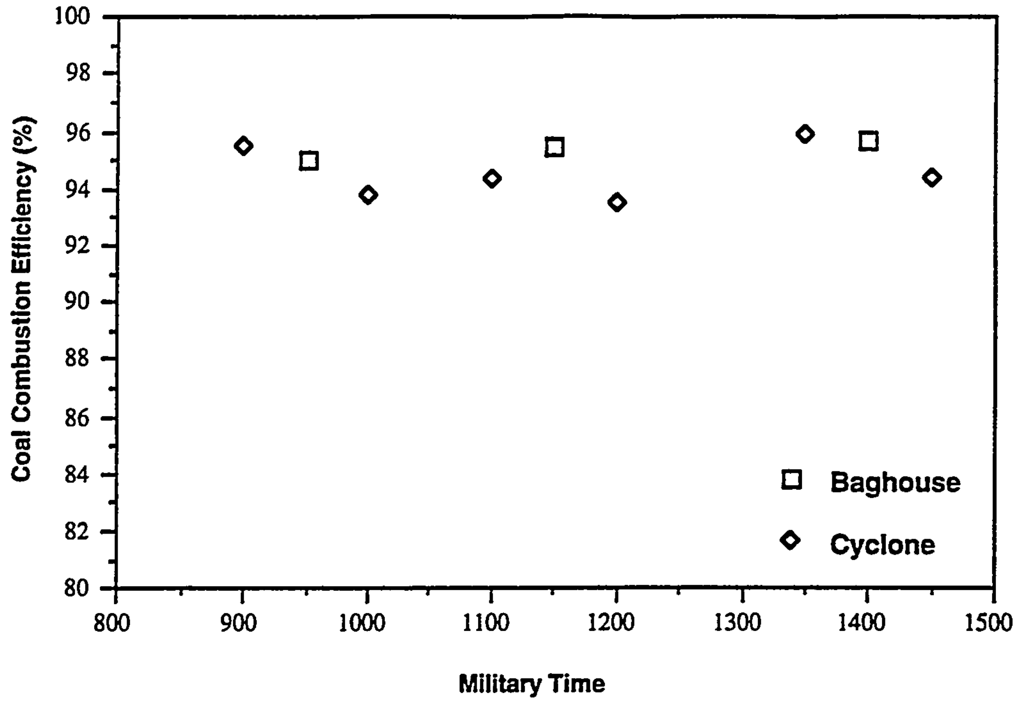
(a)



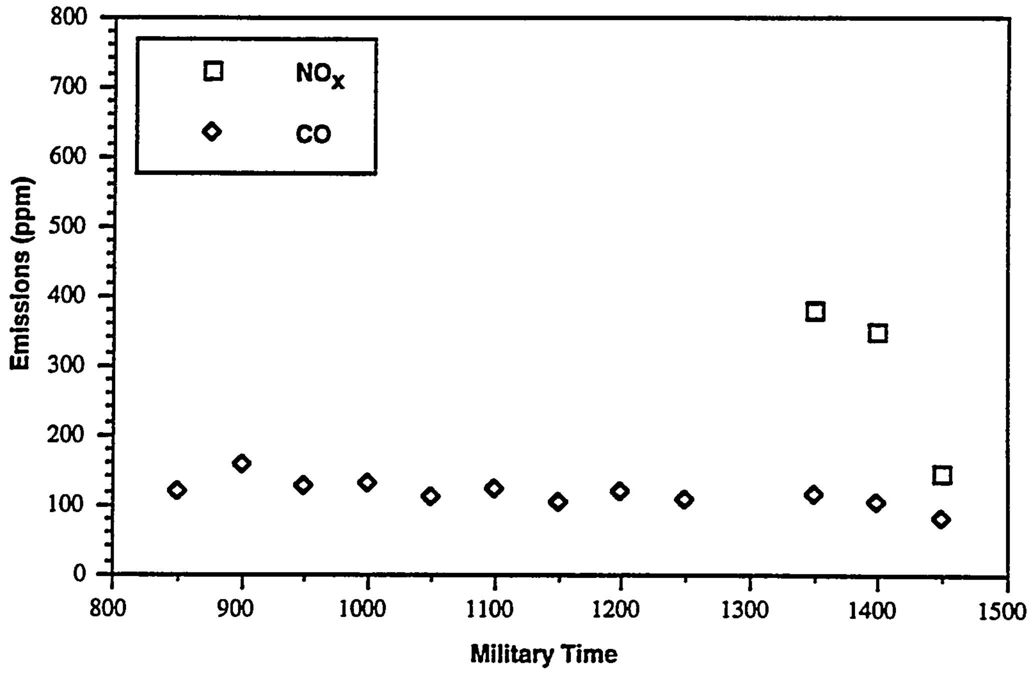
(b)

Figure 21. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/30/95

0864

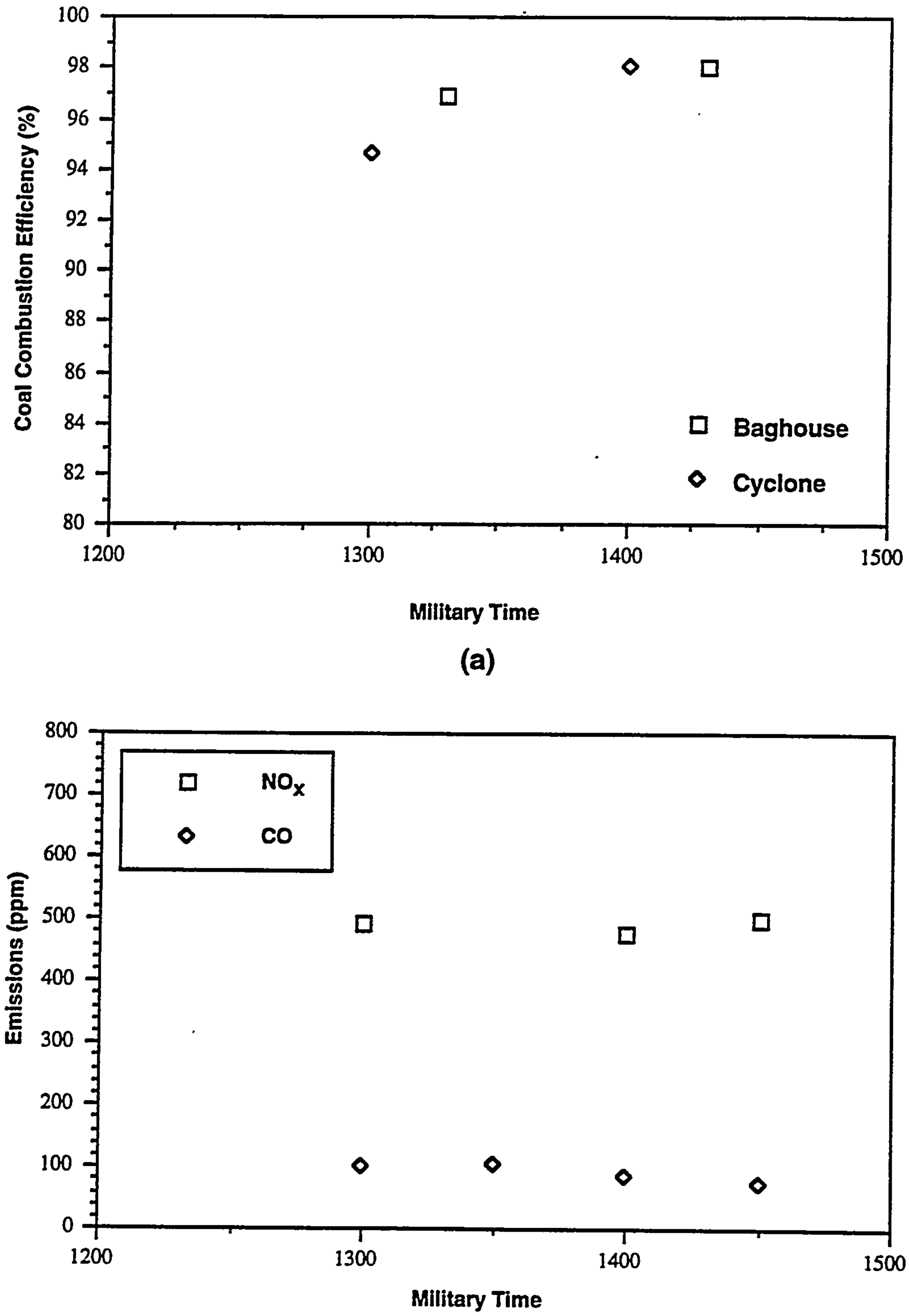


(a)



(b)

Figure 22. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 08/31/95



(a)

(b)

Figure 23. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 09/05/95

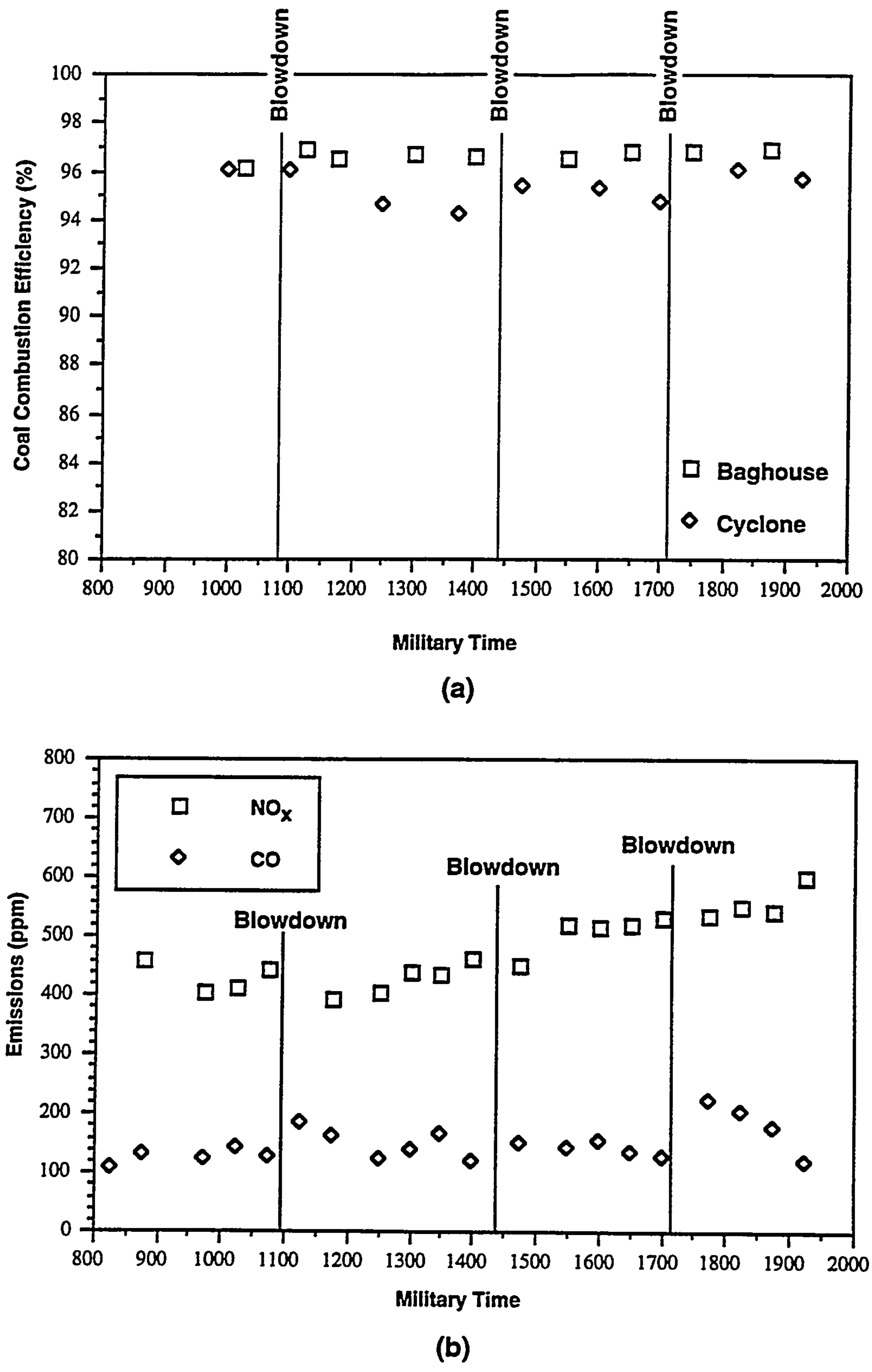


Figure 24. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 09/06/95

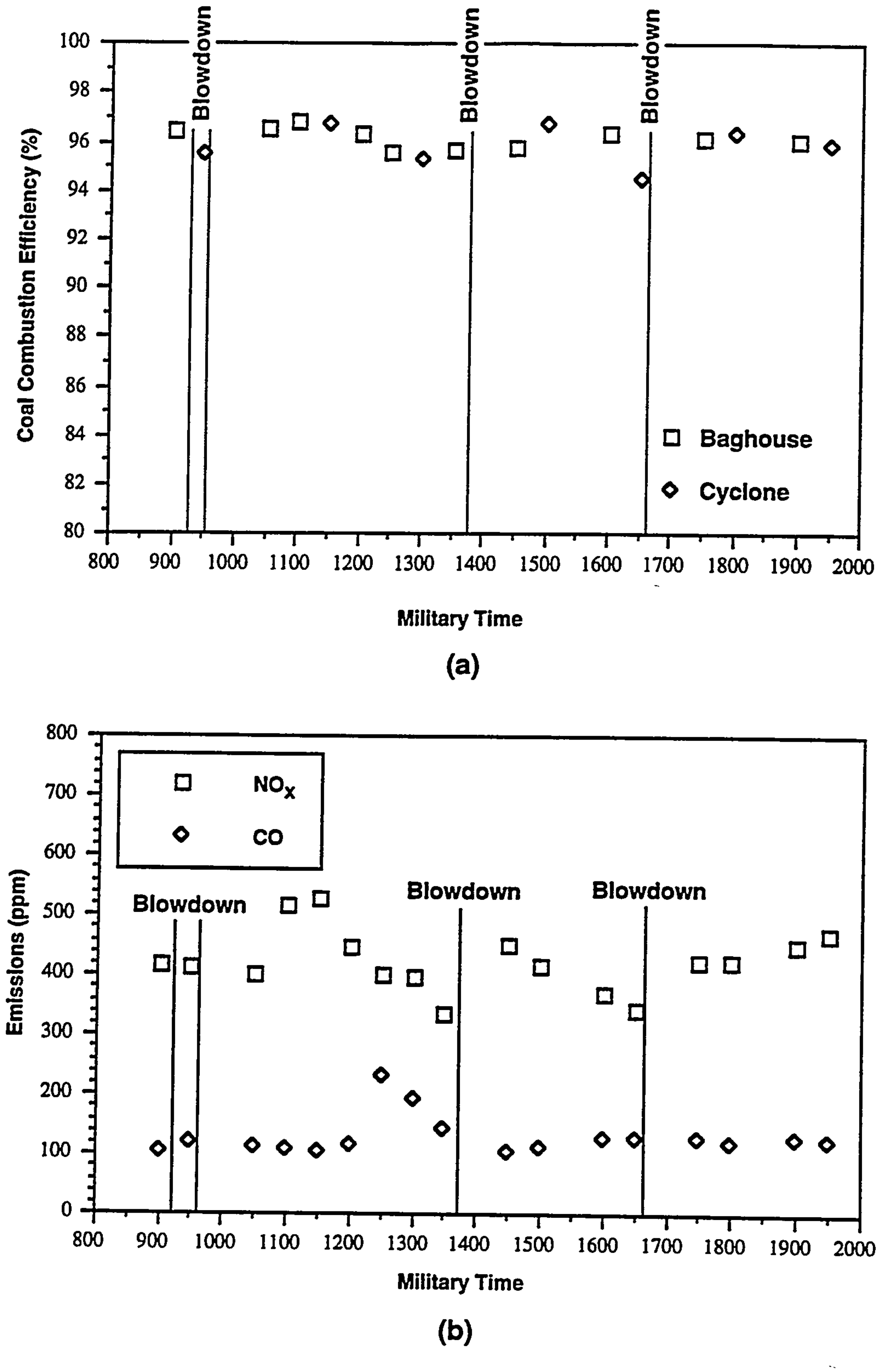


Figure 25. COAL COMBUSTION EFFICIENCY (a) AND EMISSIONS (b) AS A FUNCTION OF TIME FOR THE TESTING ON 09/07/95

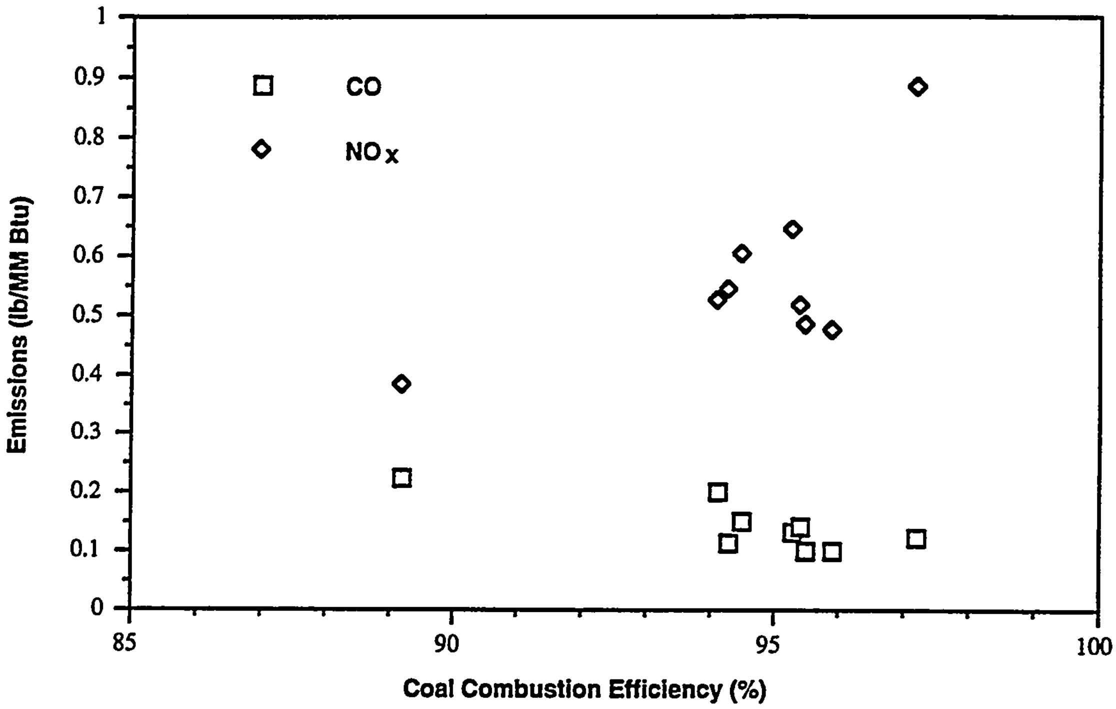


Figure 26. RELATIONSHIP BETWEEN COAL COMBUSTION EFFICIENCY AND CO AND NO_X EMISSIONS FOR THE STEADY-STATE TESTING LISTED IN TABLE 3

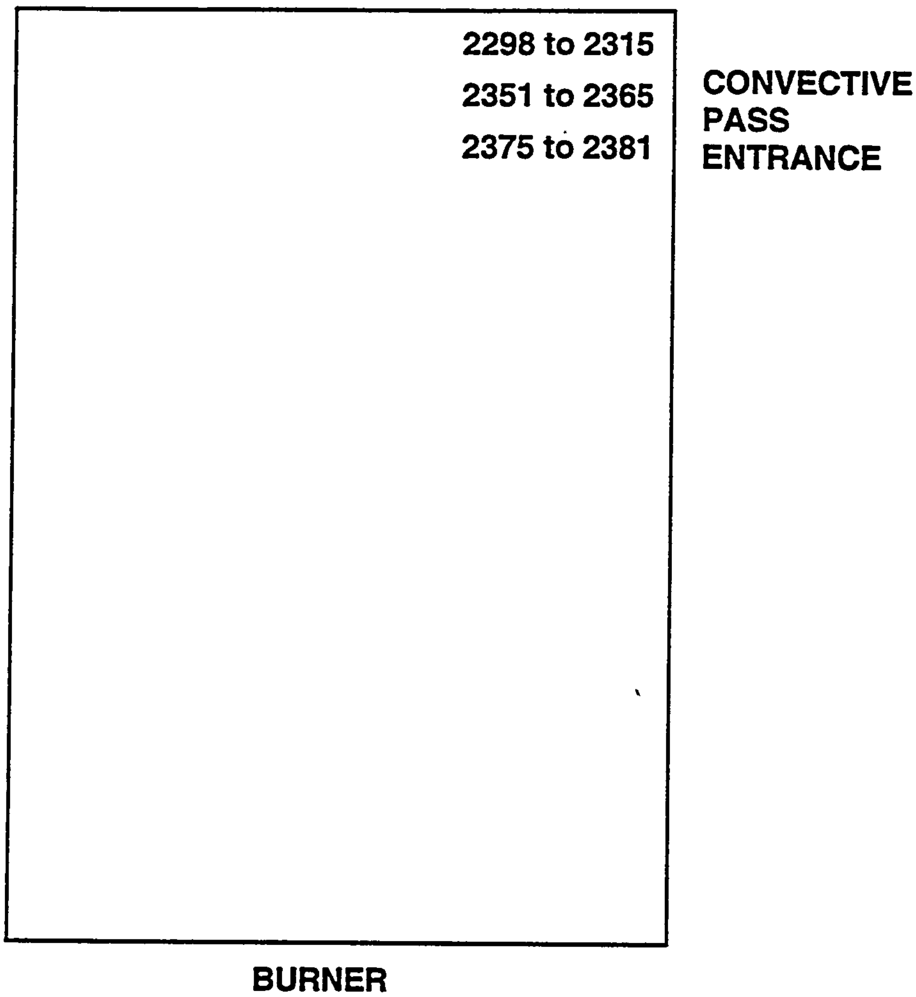


Figure 27. GAS TEMPERATURES (°F) IN THE DEMONSTRATION BOILER WHEN FIRING MICRONIZED COAL ON 08/30/95

0888

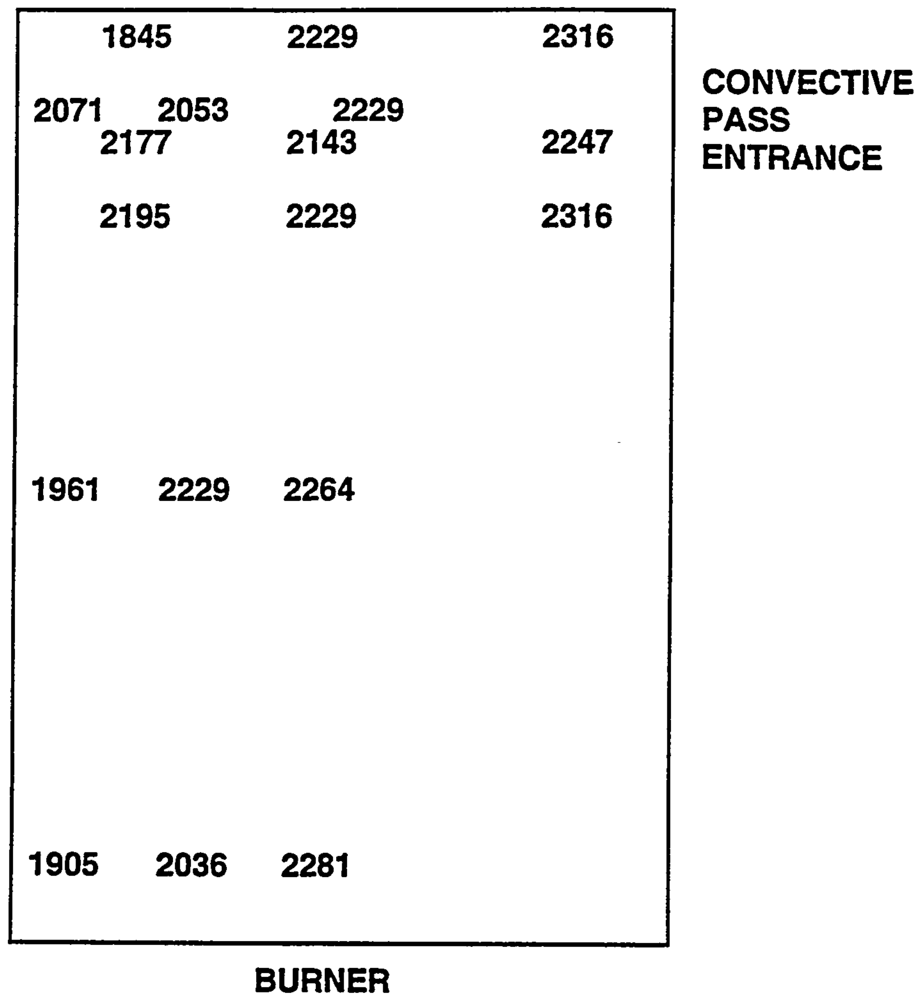


Figure 28. GAS TEMPERATURES (°F) IN THE DEMONSTRATION BOILER WHEN FIRING MICRONIZED COAL ON 08/31/95

Appendix A. Boiler Efficiency Spreadsheets

Natural Gas Baseline Tests

Test Dates

07/25/95 -- 75% load, 1% O_2

07/25/95 -- 75% load, 2% O_2

07/25/95 -- 75% load, 3% O_2

07/26/95 -- 100% load

08/01/95 -- 50% load

Micronized Coal Tests

Test Dates

08/09/95 -- Low-NO_x

08/09/95 -- High Combustion Efficiency

08/23/95

08/24/95

08/25/95

08/28/95

08/30/95

08/31/95

09/05/95

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	7/25/95	Natural Gas Baseline Testing - HEACC II			
3		100% Gas;Prim. Open, Sec. Open, Tert. 25% Open, Gas Gun -4", Coal Gun Out, 1% O2				
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	200	Enthalpy of Sat. Liq. (Btu/lb)	356		
7	Feed Water Temperature (°F)	207	Entalipy of Feed Water (Btu/lb)	175	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (%)	99.5	Steam Production Rate (PPH)	12,411		
9	Gas Temp.Leaving Boiler (°F)	517	Blow down Rate (PPH)	3,099		
10	Gas Temp. Leaving Air Heater (°F)	349	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1174	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	182	Entalpy of water at fuel inlet temp. (Btu/lb)	42	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	384	Entalpy of vapor at fuel inlet temp. (Btu/lb)	1060	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	365				
14	Mill Inlet Temperature (°F)	74				
15	Mill air flow rate (lb/h)	0	Coal Firing Rate (lb/min)	0	Gas Firing Rate (Btu/h)	567
16	Burner inlet temperature (°F)	79	Coal H.H. Value (Btu/lb)	0	Gas Cal. Value (Btu/lb)	23,346
17	**FUEL DATA**		Coal Moisture Content (%)	0		
18	**Proximate Analysis**					
19	Moisture (Wt%)		**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)					
21	Fixed Carbon (Wt%)					
22	Ash (Wt%)		Carbon	0	Methane	95.54
23			Hydrogen	0	Ethane	2.48
24	HHV (Btu/lb,. d.b)		Nitrogen	0	Propane	0
25			Sulfur	0	Butane	0.43
26			Oxygen	0	Hydrogen Sulfide	0
27			Ash	0	Carbon Dioxide	1.55
28			Total	0	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	1.1				
33	Carbon Dioxide (%)	10.6	Ash in Dry Char/Refuse	0		
34	Carbon Monoxide (PPM)	108	TOTAL CARBON CONVERSION	100.00		
35	Sulfur Dioxide (PPM)	NA	COAL CARBON CONVERSION	0.00		
36	Oxides of Nitrogen (PPM)	43				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	7/25/95				
47						
48						
49						
50						
51	**Boiler Operating Conditions**					
52						
53						
54	Total Firing Rate		13.237182	MMBtu/h		
55	Gas Support (%)		100.00	%		
56	Excess air used (%)		4.93	%		
57						
58	**Actual mass of products of combustion**	=	10864.27603	lb/lb of "as fired" fuel		
59						
60	**Theoretical flue gas composition**	%				
61	Carbon Dioxide	9.16				
62	Water vapor	18.18				
63	Oxygen	0.89				
64	Nitrogen	71.77				
65	Sulfur Dioxide (ppm)	0				
66	Total	100.00				
67	**Boiler Efficiency Details**					
68				%		
69	1. Heat loss due to Dry gas (%)			4.84		
70	2. Heat loss due to unburned carbon			0.00		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.00		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			10.40		
74	6. Heat loss due to moisture in combustion air			0.11		
75	7. Heat loss due to formation of carbon monoxide			0.03		
76	8. Heat loss due to radiation			1.41		
77	9. Heat loss due to steam drum blowdown			0.00		
78	**Total Losses**			16.80		
79	**Heat Credits**					
80	1. Heat supplied by duct burner to entering air			-83.03	Btu/lb of "as fired fuel"	
81	2. Heat supplied by primary (transport) air			0.00	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			83.14		

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	0									
23	Coal Heat Input(Btu/h)	0		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	0.00		Carbon	73.36			
25	Gas Heat Input (Btu/h)	13237182		Hydrogen	0.00		Hydrogen	24.00			
26	Total Firing Rate	13237182		Nitrogen	0.00		Nitrogen	2.60			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.00		Sulfur	0.00			
28	Gas Firing Rate (lb/h)	567		Oxygen	0.00		Oxygen	0.00			
29	Gas Support (% of Heat)	100.00		Ash	0.00		Ash	0.00			
30	Fraction of coal	0		Moisture	0		Moisture	0.05			
31	Fraction of GAS	1		Total	0		Total	100.00			
32											
33				HHV	0		HHV	23346			
34				Dry ash%	0		Dry Ash	0.00			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06113197	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.05998862	moles							
48	Sulfur= %S/(100*32) *1 mole =		0	moles							
49											
50	Oxygen required= Sum of the 3		0.12112059	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0								
52	Net Oxygen required =		0.12112059	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.57676472	moles/lb of as fired fuel							
55											
56	**Calculation of Products of combustion**										
57											
58	**Excess air used (%)**		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=								
59						4.93					
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =										
61	**Dry air in lbs/lb of "as fired" fuel**			= moles of air*29.97 =		0.60518525					
62						18.137402					
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013								
65						18.1609806					
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					19.1609806	lb/lb of fuel					
68	**Actual weight of products =**		lbs of fuel burned * Wt of Products/lb of fuel								
69			=								
70					10,864	lb of flue gas					
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											

	R	S	T	U	V	W	X	Y	Z
1	**Calculation of Theoretical Composition of Products**								
2									
3									
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)	
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06113197	9.16			11.19	
6	Water	(moles of water in fuel +moles of water in combustion air)		0.12131494	18.18			0.00	
7									
8	Oxygen			0.00596831	0.89			1.09	
9	Nitrogen			0.47902356	71.77			87.71	
10	Sulfur Dioxide			0	0			0.00	
11	Total			0.66743879	100.00			100.00	
12	Carbon Conversion	100	Carbon Conversion of Coal	NA					
13		100.00							
14	**Boiler**	**Efficiency**	**Calculations**						
15									
16	These calculations are based on ASME PTC 4.1using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	Wg' =		((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07						
21									
22		17.13060591	lb/lb of as fired fuel						
23									
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (Gas lvg temp from air heater - mill inlet temp)/HHV *100			=	4.84		
25									
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =		% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500			=	0.00		
30									
31									
32	3. Heat loss due to unburned carbon in dust						Negligible		
33									
34									
35	4. Heat loss due to moisture in "as Fired Fuel"								
36									
37	Lmf=	Moisture in Fuel	(Entahlpy of vapor at gas leaving temp - Enthalpy of water at mill inlet)/HHV*100			=	0.00		
38									
39									
40									
41	5. Heat loss due to moisture produced from burning hydrogen in fuel								
42									

	R	S	T	U	V	W	X	Y	Z
43	Lmh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-							
44									
45			Enthalpy of water at mill inlet temp)/HHV			=	10.40		
46	6. Heat loss due to moisture in combustion air								
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel								
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=						
49									
50		=	16.75	lb/lb of "as fired" fuel					
51									
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel							
53		17.57	lb						
54	Moisture in air =	0.013 lb /lb of dry air		0.22842674	lbs/lb of "as fired" fuel				
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -							
56			enthalpy of vapor at mill inlet temp.)						
57							0.11		
58									
59	7. Heat loss due to formation of carbon monoxide								
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel				=	0.03		
61									
62									
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.41		
64									
65									
66									
67									
68	Total Losses (%)						16.80	%	
69	HEAT CREDITS								
70									
71	1. Heat supplied by duct burner to entering air					-83.03	Btu/lb of "as Fired" Fuel		
72	2. Heat supplied by primary (transport) air					0.00	Btu/lb of "as Fired" Fuel		
73									
74	**Boiler Efficiency (%)=**								
75							83.14	%	
76	**Combustion Air Flow (%) =**						10,092	lb/h	
77									
78									
79									
80									
81									
82									
83									

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	7/25/95	Natural Gas Baseline Testing - HEACC II			
3		100% Gas;	Prim. Open, Sec. Open, Tert. 25% Open, Gas Gun -4", Coal Gun Out, 2% O2			
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	200	Enthalpy of Sat. Liq. (Btu/lb)	356		
7	Feed Water Temperature (°F)	207	Entahlpy of Feed Water (Btu/lb)	175	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (%)	99.5	Steam Production Rate (PPH)	12,387		
9	Gas Temp.Leaving Boiler (°F)	520	Blow down Rate (PPH)	3,099		
10	Gas Temp. Leaving Air Heater (°F)	351	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1175	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	179	Entalpy of water at fuel inlet temp. (Btu/lb)	43	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	384	Entalpy of vapor at fuel inlet temp. (Btu/lb)	1060	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	364				
14	Mill Inlet Temperature (°F)	75				
15	Mill air flow rate (lb/h)	0	Coal Firing Rate (lb/min)	0	Gas Firing Rate (Btu/h)	567
16	Burner Inlet temperature (°F)	79	Coal H.H. Value (Btu/lb)	0	Gas Cal. Value (Btu/lb)	23,346
17	**FUEL DATA**		Coal Moisture Content (%)	0		
18	**Proximate Analysis**					
19	Moisture (Wt%)		**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)					
21	Fixed Carbon (Wt%)					
22	Ash (Wt%)		Carbon	0	Methane	95.54
23			Hydrogen	0	Ethane	2.48
24	HHV (Btu/lb,. d.b)		Nitrogen	0	Propane	0
25			Sulfur	0	Butane	0.43
26			Oxygen	0	Hydrogen Sulfide	0
27			Ash	0	Carbon Dioxide	1.55
28			Total	0	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	2.1				
33	Carbon Dioxide (%)	10.2	Ash in Dry Char/Refuse	0		
34	Carbon Monoxide (PPM)	49	TOTAL CARBON CONVERSION	100.00		
35	Sulfur Dioxide (PPM)	NA	COAL CARBON CONVERSION	0.00		
36	Oxides of Nitrogen (PPM)	44				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	7/25/95				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		13.237182	MMBtu/h		
55	Gas Support (%)		100.00	%		
56	Excess air used (%)		9.96	%		
57						
58	Actual mass of products of combustion	=	11358.41111	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	8.78				
62	Water vapor	17.43				
63	Oxygen	1.73				
64	Nitrogen	72.07				
65	Sulfur Dioxide (ppm)	0				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			5.05		
70	2. Heat loss due to unburned carbon			0.00		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.00		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			10.40		
74	6. Heat loss due to moisture in combustion air			0.12		
75	7. Heat loss due to formation of carbon monoxide			0.02		
76	8. Heat loss due to radiation			1.41		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			16.99		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-91.59	Btu/lb of "as fired fuel"	
81	2. Heat supplied by primary (transport) air			0.00	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			82.94		

Boiler Performance Calculations

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
6	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
7	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
8	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
9	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
10	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
11	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
12	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
13	Total	100									
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	0									
23	Coal Heat Input(Btu/h)	0		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	0.00		Carbon	73.36			
25	Gas Heat Input (Btu/h)	13237182		Hydrogen	0.00		Hydrogen	24.00			
26	Total Firing Rate	13237182		Nitrogen	0.00		Nitrogen	2.60			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.00		Sulfur	0.00			
28	Gas Firing Rate (lb/h)	567		Oxygen	0.00		Oxygen	0.00			
29	Gas Support (% of Heat)	100.00		Ash	0.00		Ash	0.00			
30	Fraction of coal	0		Moisture	0		Moisture	0.05			
31	Fraction of GAS	1		Total	0		Total	100.00			
32											
33				HHV	0		HHV	23346			
34				Dry ash%	0		Dry Ash	0.00			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06113197	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.05998862	moles							
48	Sulfur= %S/(100*32) *1 mole =		0	moles							
49											
50	Oxygen required= Sum of the 3		0.12112059	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0								
52	Net Oxygen required =		0.12112059	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.57676472	moles/lb of as fired fuel							
55											
56	**Calculation of Products of combustion**										
57											
58	**Excess air used (%)**		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2)=			9.96					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.63422626					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		19.007761					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			19.0324711					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					20.0324711	lb/lb of fuel					
68	**Actual weight of products =**		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		11,358	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											

	R	S	T	U	V	W	X	Y	Z
1	Calculation of Theoretical Composition of Products								
2									
3									
4					Wet Flue Gas	Composition (%)		Dry Flue Gas	Comp. (%)
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06113197	8.78			10.63	
6	Water	(moles of water in fuel +moles							
7		of water in combustion air)		0.1213778	17.43			0.00	
8	Oxygen			0.01206692	1.73			2.10	
9	Nitrogen			0.50196596	72.07			87.27	
10	Sulfur Dioxide			0	0			0.00	
11	Total			0.69654265	100.00			100.00	
12	Carbon Conversion	100	Carbon Conversion of Coal	NA					
13		100.00							
14	**Boiler**	**Efficiency**	**Calculations**						
15									
16	These calculations are based on ASME PTC 4.1using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07							
21									
22		17.7975154	lb/lb of as fired fuel						
23									
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (Gas lvg temp from			=	5.05		
25			air heater - mill Inlet temp)/HHV *100						
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	0.00		
30									
31									
32	3. Heat loss due to unburned carbon in dust						Negligible		
33									
34									
35	4. Heat loss due to moisture in "as Fired Fuel"								
36									
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -							
38			Enthalpy of water at mill inlet)/HHV*100			=	0.00		
39									
40									
41	5. Heat loss due to moisture produced from burning hydrogen in fuel								
42									

	R	S	T	U	V	W	X	Y	Z
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-							
44			Enthalpy of water at mill inlet temp)/HHV			=			
45							10.40		
46	6. Heat loss due to moisture in combustion air								
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel								
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=						
49									
50		=	16.75	lb/lb of "as fired" fuel					
51									
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel							
53		18.41	lb						
54	Moisture in air =	0.013 lb /lb of dry air		0.23938825	lbs/lb of "as fired" fuel				
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -							
56			enthalpy of vapor at mill inlet temp.)						
57							0.12		
58									
59	7. Heat loss due to formation of carbon monoxide								
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel				=	0.02		
61									
62									
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.41		
64									
65									
66									
67									
68	Total Losses (%)						16.99	%	
69	HEAT CREDITS								
70									
71	1. Heat supplied by duct burner to entering air					-91.59	Btu/lb of "as Fired" Fuel		
72	2. Heat supplied by primary (transport) air					0.00	Btu/lb of "as Fired" Fuel		
73									
74	**Boiler Efficiency (%)=**						82.94	%	
75									
76	**Combustion Air Flow (%) =**						10,577	lb/h	
77									
78									
79									
80									
81									
82									
83									

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	7/25/95	Natural Gas Baseline Testing - HEACC II			
3		100% Gas;Prim. Open, Sec. Open, Tert. 25% Open, Gas Gun -4", Coal Gun Out, 3% O2				
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	199	Enthalpy of Sat. Liq. (Btu/lb)			
7	Feed Water Temperature (°F)	206	Entahlpy of Feed Water (Btu/lb)	355		
8	Steam Quality (%)	99.5	Steam Production Rate (PPH)	175	(Sat. liquid @ Feed water temp.)	
9	Gas Temp.Leaving Boiler (°F)	525	Blow down Rate (PPH)	12,404		
10	Gas Temp. Leaving Air Heater (°F)	354	Enthalpy of water vapor at Glvg Temp (Btu/lb)	3,093		
11	Air Temp Entering Air Heater (°F)	175	Entalpy of water at fuel inlet temp. (Btu/lb)	1176	(Sup. steam @ 1psia&gas lvg temp)	
12	Air temp leaving Air Pre Heater (°F)	383	Entalpy of vapor at fuel inlet temp. (Btu/lb)	53	(Sat. liq. @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	363		1060	(Sat. vapor @ mill inlet temp.)	
14	Mill Inlet Temperature (°F)	85				
15	Mill air flow rate (lb/h)	0	Coal Firing Rate (lb/min)			
16	Burner Inlet temperature (°F)	79	Coal H.H. Value (Btu/lb)	0	Gas Firing Rate (Btu/h)	567
17	**FUEL DATA**		Coal Moisture Content (%)	0	Gas Cal. Value (Btu/lb)	23,346
18	**Proximate Analysis**			0		
19	Moisture (Wt%)		**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)					
21	Fixed Carbon (Wt%)					
22	Ash (Wt%)		Carbon			
23			Hydrogen	0	Methane	95.54
24	**HHV (Btu/lb, d.b)**		Nitrogen	0	Ethane	2.48
25			Sulfur	0	Propane	0
26			Oxygen	0	Butane	0.43
27			Ash	0	Hydrogen Sulfide	0
28			Total	0	Carbon Dioxide	1.55
29				0	Nitrogen	
30	**Flue Gas Analysis**				Others	
31					Total	100
32	Oxygen (%)	3.1			Moisture (wt%)	0.05
33	Carbon Dioxide (%)	9.6	Ash in Dry Char/Refuse			
34	Carbon Monoxide (PPM)	45	TOTAL CARBON CONVERSION	0		
35	Sulfur Dioxide (PPM)	NA	COAL CARBON CONVERSION	100.00		
36	Oxides of Nitrogen (PPM)	44		0.00		
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43						
44			Summary of Boiler Performance			
45						
46	Date of Operation	7/25/95				
47						
48						
49						
50						
51	**Boiler Operating Conditions**					
52						
53						
54	Total Firing Rate		13.237182	MMBtu/h		
55	Gas Support (%)		100.00	%		
56	**Excess air used (%)**		15.53	%		
57						
58	**Actual mass of products of combustion**	=	11904.65983	lb/lb of "as fired" fuel		
59						
60	**Theoretical flue gas composition**	%				
61	Carbon Dioxide	8.39				
62	Water vapor	16.67				
63	Oxygen	2.58				
64	Nitrogen	72.36				
65	Sulfur Dioxide (ppm)	0				
66	Total	100.00				
67	**Boiler Efficiency Details**					
68				%		
69	1. Heat loss due to Dry gas (%)			5.22		
70	2. Heat loss due to unburned carbon			0.00		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.00		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			10.31		
74	6. Heat loss due to moisture in combustion air			0.12		
75	7. Heat loss due to formation of carbon monoxide			0.01		
76	8. Heat loss due to radiation			1.41		
77	9. Heat loss due to steam drum blowdown			0.00		
78	**Total Losses**			17.08		
79	**Heat Credits**					
80	1. Heat supplied by duct burner to entering air			-96.23	Btu/lb of "as fired fuel"	
81	2. Heat supplied by primary (transport) air			0.00	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			82.84		

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
6	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
7	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
8	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
9	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
10	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
11	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
12	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
13	Total	100									
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	0									
23	Coal Heat Input(Btu/h)	0		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	0.00		Carbon	73.36			
25	Gas Heat Input (Btu/h)	13237182		Hydrogen	0.00		Hydrogen	24.00			
26	Total Firing Rate	13237182		Nitrogen	0.00		Nitrogen	2.60			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.00		Sulfur	0.00			
28	Gas Firing Rate (lb/h)	567		Oxygen	0.00		Oxygen	0.00			
29	Gas Support (% of Heat)	100.00		Ash	0.00		Ash	0.00			
30	Fraction of coal	0		Moisture	0		Moisture	0.05			
31	Fraction of GAS	1		Total	0		Total	100.00			
32											
33				HHV	0		HHV	23346			
34				Dry ash%	0		Dry Ash	0.00			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06113197	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.05998862	moles							
48	Sulfur= %S/(100*32) *1 mole =		0	moles							
49											
50	Oxygen required= Sum of the 3		0.12112059	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0								
52	Net Oxygen required =		0.12112059	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.57676472	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			15.53					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.66633006					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		19.9699118					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			19.9958727					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					20.9958727	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		11,905	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											

	R	S	T	U	V	W	X	Y	Z
1	**Calculation of Theoretical Composition of Products**								
2									
3									
4									
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06113197	Wet Flue Gas 8.39	Compositon (%)		Dry Flue Gas 10.07	Comp. (%)
6	Water	(moles of water in fuel +moles							
7		of water in combustion air)		0.12144729	16.67			0.00	
8	Oxygen			0.01880872	2.58			3.10	
9	Nitrogen			0.52732796	72.36			86.84	
10	Sulfur Dioxide			0	0			0.00	
11	Total			0.72871594	100.00			100.00	
12	Carbon Conversion	100	Carbon Conversion of Coal	NA					
13		100.00							
14	**Boiler**	**Efficiency**	**Calculations**						
15									
16	These calculations are based on ASME PTC 4.1using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07							
21									
22		18.87437722	lb/lb of as fired fuel						
23									
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (Gas lvg temp from						
25			air heater - mill inlet temp)/HHV *100			=	5.22		
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	0.00		
30									
31									
32	3. Heat loss due to unburned carbon in dust						Negligible		
33									
34									
35	4. Heat loss due to moisture in "as Fired Fuel"								
36									
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -							
38			Enthalpy of water at mill inlet)/HHV*100			=	0.00		
39									
40									
41	5. Heat loss due to moisture produced from burning hydrogen in fuel								
42									

	R	S	T	U	V	W	X	Y	Z
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-							
44									
45			Enthalpy of water at mill inlet temp)/HHV			=	10.31		
46	6. Heat loss due to moisture in combustion air								
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel								
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=						
49									
50		=							
51			16.75	lb/lb of "as fired" fuel					
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel							
53		19.35	lb						
54	Moisture in air =	0.013 lb /lb of dry air		0.2515058	lbs/lb of "as fired" fuel				
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -							
56			enthalpy of vapor at mill inlet temp.)						
57							0.12		
58									
59	7. Heat loss due to formation of carbon monoxide								
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel				=			
61							0.01		
62									
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)						
64							1.41		
65									
66									
67									
68	Total Losses (%)								
69	HEAT CREDITS						17.08	%	
70									
71	1. Heat supplied by duct burner to entering air								
72	2. Heat supplied by primary (transport) air					-96.23	Btu/lb of "as Fired" Fuel		
73						0.00	Btu/lb of "as Fired" Fuel		
74	**Boiler Efficiency (%)=**								
75							82.84	%	
76	**Combustion Air Flow (%) =**								
77							11,112	lb/h	
78									
79									
80									
81									
82									
83									

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	7/26/95	Natural Gas Baseline Testing - HEACC II			
3		100% Gas;	Prim. Open, Sec. Open, Tert. Open, Gas Gun +4", Coal Gun Out, 1.5% O2			
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	204	Enthalpy of Sat. Liq. (Btu/lb)	357		
7	Feed Water Temperature (°F)	217	Entahlpy of Feed Water (Btu/lb)	185	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (%)	100.23	Steam Production Rate (PPH)	15,659		
9	Gas Temp.Leaving Boiler (°F)	576	Blow down Rate (PPH)	3,128		
10	Gas Temp. Leaving Air Heater (°F)	390	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1192	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	173	Entalpy of water at fuel inlet temp. (Btu/lb)	59	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	409	Entalpy of vapor at fuel inlet temp. (Btu/lb)	1060	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	391				
14	Mill Inlet Temperature (°F)	91				
15	Mill air flow rate (lb/h)	0	Coal Firing Rate (lb/min)	0	Gas Firing Rate (Btu/h)	732
16	Burner inlet temperature (°F)	89	Coal H.H. Value (Btu/lb)	0	Gas Cal. Value (Btu/lb)	23,346
17	**FUEL DATA**		Coal Moisture Content (%)	0		
18	**Proximate Analysis**					
19	Moisture (Wt%)		**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)					
21	Fixed Carbon (Wt%)					
22	Ash (Wt%)		Carbon	0	Methane	95.54
23			Hydrogen	0	Ethane	2.48
24	**HHV (Btu/lb,. d.b)**		Nitrogen	0	Propane	0
25			Sulfur	0	Butane	0.43
26			Oxygen	0	Hydrogen Sulfide	0
27			Ash	0	Carbon Dioxide	1.55
28			Total	0	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	1.5				
33	Carbon Dioxide (%)	11	Ash in Dry Char/Refuse	0		
34	Carbon Monoxide (PPM)	37	TOTAL CARBON CONVERSION	100.00		
35	Sulfur Dioxide (PPM)	NA	COAL CARBON CONVERSION	0.00		
36	Oxides of Nitrogen (PPM)	26				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	7/26/95				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate					
55	Gas Support (%)		17.089272	MMBtu/h		
56	Excess air used (%)		100.00	%		
57			6.94	%		
58	Actual mass of products of combustion	=				
59			14280.2447	lb/lb of "as fired" fuel		
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	9.00				
62	Water vapor	17.87				
63	Oxygen	1.24				
64	Nitrogen	71.89				
65	Sulfur Dioxide (ppm)	0				
66	Total	100.00				
67	Boiler Efficiency Details					
68						
69	1. Heat loss due to Dry gas (%)			%		
70	2. Heat loss due to unburned carbon			5.09		
71	3. Heat loss due to unburned carbon in dust			0.00		
72	4. Heat loss due to moisture in "as Fired Fuel"			Negligible		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			0.00		
74	6. Heat loss due to moisture in combustion air			10.41		
75	7. Heat loss due to formation of carbon monoxide			0.13		
76	8. Heat loss due to radiation			0.01		
77	9. Heat loss due to steam drum blowdown			1.27		
78	Total Losses			0.00		
79	Heat Credits			16.91		
80	1. Heat supplied by duct burner to entering air					
81	2. Heat supplied by primary (transport) air			-80.16	Btu/lb of "as fired fuel"	
82				0.00	Btu/lb of "as fired fuel"	
83	BOILER EFFICIENCY (%)			83.03		

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	0									
23	Coal Heat Input(Btu/h)	0		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	0.00		Carbon	73.36			
25	Gas Heat Input (Btu/h)	17089272		Hydrogen	0.00		Hydrogen	24.00			
26	Total Firing Rate	17089272		Nitrogen	0.00		Nitrogen	2.60			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.00		Sulfur	0.00			
28	Gas Firing Rate (lb/h)	732		Oxygen	0.00		Oxygen	0.00			
29	Gas Support (% of Heat)	100.00		Ash	0.00		Ash	0.00			
30	Fraction of coal	0		Moisture	0		Moisture	0.05			
31	Fraction of GAS	1		Total	0		Total	100.00			
32											
33				HHV	0		HHV	23346			
34				Dry ash%	0		Dry Ash	0.00			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06113197	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.05998862	moles							
48	Sulfur= %S/(100*32) *1 mole =		0	moles							
49											
50	Oxygen required= Sum of the 3		0.12112059	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0								
52	Net Oxygen required =		0.12112059	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.57676472	moles/lb of as fired fuel							
55											
56	**Calculation of Products of combustion**										
57											
58	**Excess air used (%)**		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			6.94					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.61676681					
61	**Dry air in lbs/lb of "as fired" fuel**			= moles of air*29.97 =		18.4845012					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			18.508531					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					19.508531	lb/lb of fuel					
68	**Actual weight of products =**		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		14,280	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											

	R	S	T	U	V	W	X	Y	Z
1	**Calculation of Theoretical Composition of Products**								
2									
3									
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)	
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06113197	9.00			10.96	
6	Water	(moles of water in fuel +moles							
7		of water in combustion air)		0.12134001	17.87			0.00	
8	Oxygen			0.00840044	1.24			1.51	
9	Nitrogen			0.48817299	71.89			87.53	
10	Sulfur Dioxide			0	0			0.00	
11	Total			0.67904541	100.00			100.00	
12	Carbon Conversion	100	Carbon Conversion of Coal	NA					
13		100.00							
14	**Boiler**	**Efficiency**	**Calculations**						
15									
16	These calculations are based on ASME PTC 4.1using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07							
21									
22		16.56327899	lb/lb of as fired fuel						
23									
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (Gas lvg temp from			=	5.09		
25			air heater - mill inlet temp)/HHV *100						
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	0.00		
30									
31									
32	3. Heat loss due to unburned carbon in dust						Negligible		
33									
34									
35	4. Heat loss due to moisture in "as Fired Fuel"								
36									
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -							
38			Enthalpy of water at mill inlet)/HHV*100			=	0.00		
39									
40									
41	5. Heat loss due to moisture produced from burning hydrogen in fuel								
42									

	R	S	T	U	V	W	X	Y	Z
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-							
44			Enthalpy of water at mill inlet temp)/HHV						
45						=	10.41		
46	6. Heat loss due to moisture in combustion air								
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel								
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=						
49									
50		=	16.75	lb/lb of "as fired" fuel					
51									
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel							
53		17.91	lb						
54	Moisture in air =	0.013 lb /lb of dry air		0.23279819	lbs/lb of "as fired" fuel				
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -							
56			enthalpy of vapor at mill inlet temp.)						
57							0.13		
58									
59	7. Heat loss due to formation of carbon monoxide								
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel				=	0.01		
61									
62									
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.27		
64									
65									
66									
67									
68	Total Losses (%)						16.91	%	
69	HEAT CREDITS								
70									
71	1. Heat supplied by duct burner to entering air					-80.16	Btu/lb of "as Fired" Fuel		
72	2. Heat supplied by primary (transport) air					0.00	Btu/lb of "as Fired" Fuel		
73									
74	Boiler Efficiency (%)=								
75							83.03	%	
76	Combustion Air Flow (%) =								
77							13,279	lb/h	
78									
79									
80									
81									
82									
83									

Demonstration		**Boiler Data**			
Date of Operation	1-Aug	Test Matrix #burner characterization			
50% Load Gas; HEACC II Burner, Prim max, Sec max, Tert 75%, Gas Gun +4", Coal Gun Out, 1.8% O2					
Pressures and Temperatures		**Steam Data**			
Drum Steam Pressure (Psig)	191.35	Enthalpy of Sat. Liq. (Btu/lb)	353.52		
Feed Water Temperature (°F)	217.26	Enthalpy of Feed Water (Btu/lb)	185.47	(Sat. liquid @ Feed water temp.)	
Steam Quality (% moisture)	99.97	Steam Production Rate (PPH)	8609.15		
Gas Temp Leaving Boiler (°F)	477	Blow down Rate (PPH)	3054.25		
Gas Temp. Leaving Air Heater (°F)	337	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1168.04	(Sup. steam @ 1psia&gas lvg temp)	
Air Temp Entering Air Heater (°F)	211	Enthalpy of water at fuel inlet temp. (Btu/lb)	51.71	(Sat. liq. @ mill inlet temp)	
Air temp leaving Air Pre Heater (°F)	385	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1060.40	(Sat. vapor @ mill inlet temp.)	
Air Temp Entering Boiler (°F)	363				
Mill Inlet Temperature (°F)	84				
Mill air flow rate (lb/h)	0	Coal Firing Rate (lb/h)	0	Gas Firing Rate (lb/h)	367.62
Burner inlet temperature (°F)	97	Coal HHV. Value (Btu/lb)	13331	Gas Cal. Value (Btu/lb)	23346
FUEL DATA		Coal Moisture Content (%)	3.42		
Proximate Analysis					
Moisture (Wt%)	3.42	**Ultimate Analysis (Wt%, d.b)**		**Gas Analysis (Dry Vol%)**	
Volatile Matter (Wt%)	30.82				
Fixed Carbon (Wt%)	59.07				
Ash (Wt%)	6.03	Carbon	79.13	Methane	95.54
		Hydrogen	5.09	Ethane	2.48
HHV (Btu/lb, d.b)	13803	Nitrogen	1.5	Propane	0
		Sulfur	0.52	Butane	0.43
		Oxygen	6.83	Hydrogen Sulfide	0
		Ash	6.03	Carbon Dioxide	1.55
		Total	99.1	Nitrogen	
				Others	
Flue Gas Analysis				Total	100
				Moisture (wt%)	0.05
Oxygen (%)	1.80				
Carbon Dioxide (%)	11.21	Ash in Dry Char/Refuse	100		
Carbon Monoxide (PPM)	73.37	TOTAL CARBON CONVERSION	100.00		
Sulfur Dioxide (PPM)	3.77	COAL CARBON CONVERSION	100.00		
Oxides of Nitrogen (PPM)	47.76				

		Summary of Boiler Performance		
Date of Operation	1-Aug			
Boiler Operating Conditions				
Total Firing Rate		8.58255652	MMBtu/h	
Gas Support (%)		100.00	%	
Excess air used (%)		8.49	%	
Actual mass of products of combustion =		7270.402874	lb/lb of "as fired" fuel	
Theoretical flue gas composition	%			
Carbon Dioxide	8.89			
Water vapor	17.64			
Oxygen	1.49			
Nitrogen	71.98			
Sulfur Dioxide (ppm)	0			
Total	100.0			
Boiler Efficiency Details				
			%	
1. Heat loss due to Dry gas (%)			4.24	
2. Heat loss due to unburned carbon			0.00	
3. Heat loss due to unburned carbon in dust			Negligible	
4. Heat loss due to moisture in "as Fired Fuel"			0.00	
5. Heat loss due to moisture produced from burning hydrogen in fuel			10.25	
6. Heat loss due to moisture in combustion air			0.11	
7. Heat loss due to formation of carbon monoxide			0.02	
8. Heat loss due to radiation			1.69	
9. Heat loss due to steam drum blowdown			0.00	
Total Losses			16.31	
Heat Credits				
1. Heat supplied by duct burner to entering air			-103.06	Btu/lb of "as fired fuel"
2. Heat supplied by mill to primary (transport) air			0.00	Btu/lb of "as fired fuel"
BOILER EFFICIENCY (%)			83.61	

Boiler Performance Calculations

Conversion of Gas Composition from Volume % to Wt%

Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)	lbs in each Cu.ft of gas
Methane	95.54	0.01246	0.0405663
Ethane	2.48	0.08029	0.0019912
Propane	0	0.1196	0
Butane	0.43	0.1582	0.0006803
Hydrogen Sulfide	0	0.09109	0
Carbon Dioxide	0	0.117	0
Nitrogen	1.55	0.07439	0.001153
Total	**100**		
		Density of N. gas (lb/cu.ft) =	**0.0444**

N. Gas Composition (Wt%, d.b)		As Fired (wt%)
Carbon	73.40	73.3583626
Hydrogen	24.01	23.9954486
Nitrogen	2.60	2.59618878
Sulfur	0.00	0
Oxygen	0.00	0
Moisture	0.00	0.05
Total=	100.00	100.00

Determination of Percent Gas Support

Coal Firing Rate (lb/h)	0
Coal Heat Input(Btu/h)	0
Gas Heat Input (Btu/h)	8582456.5
Total Firing Rate	8582456.5
Gas Calorific Value (Btu/lb)	23346
Gas Firing Rate (lb/h)	367.62
Gas Support (% of Heat)	**100.00**
Fraction of coal	0
Fraction of GAS	1

As Fired Coal Composition (Wt)	
Carbon	76.42
Hydrogen	4.92
Nitrogen	1.45
Sulfur	0.50
Oxygen	6.60
Ash	5.82
Moisture	3.42
Total	99.13
HHV	13330.937
Dry ash%	6.03

"As Fired" Fuel (coal+nat. gas) Composition (Wt%)	
Carbon	73.36
Hydrogen	24.00
Nitrogen	2.60
Sulfur	0.00
Oxygen	0.00
Ash	0.00
Moisture	0.05
Total	100.00
HHV	23,346
Dry Ash	0.00

Calculation of Air Requirement and Theoretical Products of Composition					
		Theoretical Oxygen Requirement			
Carbon= %C/(100*12) *1mole =		0.06113197	moles		
Hydrogen= %H/(100*2)*0.5 mole =		0.05998862	moles		
Sulfur= %S/(100*32) *1 mole =		0	moles		
Oxygen required= Sum of the 3		0.12112059	moles		
Oxygen available in the Fuel= %O/(100*32) =		0			
Net Oxygen required =		0.12112059	moles		
Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =					
		0.57676472	moles/lb of as fired fuel		
Calculation of Products of combustion					
Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			8.49
Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.62571148
Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		**18.752573**
Actual wet air used/lb of 'as fired' fuel (assuming 60% R.H and 80°F)=					
	=	lbs of dry air * 1.0013			18.7769514
Weight of products of combustion = Actual wet air used + weight of fuel=					
				19.776951	lb/lb of fuel
Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel			
		=		**7270.4**	**lb/hr of flue gas**

Calculation of Theoretical Composition of Products

			Wet Flue Gas Composition (%)	Dry Flue Gas Comp. (%)
Carbon Dioxide	(=moles of carbon /lb of fuel)	0.06113197	8.89	
Water	(moles of water in fuel + moles of water in combustion air)	0.12135937	17.64	10.79
Oxygen		0.01027882	1.49	0.00
Nitrogen		0.49523928	71.98	1.81
Sulfur Dioxide		0	0	87.40
Total		0.68800944	100.00	0.00
				100.00

Boiler Efficiency Calculations

These calculations are based on ASME PTC 4.1using heat loss method

1. Pounds of dry gas per pound of "as fired" composite fuel

Wg' = ((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07

16.27261317 lb/lb of as fired fuel

1. Heat loss due to dry gas (%) Lwg' = Wg' * 0.24 * (359-75)/HHV *100 = 4.24

2. Heat loss due to unburned carbon = 0.00

Luc = % Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500

3. Heat loss due to unburned carbon in dust Negligible

4. Heat loss due to moisture in "as Fired Fuel" = 0.00

Lmf= Moisture in Fuel (Enthalpy of vapor at gas leaving temp - Enthalpy of water at mill inlet)/HHV*100

5. Heat loss due to moisture produced from burning hydrogen in fuel = 10.25

Lmfh=	8.936 * % hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-						
		Enthalpy of water at mill inlet temp)/HHV					
6. Heat loss due to moisture in combustion air					=	0.11	
Theoretical lb of air required for complete combustion/lb of "as fired" fuel							
	=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=					
	=	16.75	lb/lb of "as fired" fuel				
Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel						
	18.17	lb					
Moisture in air =	0.013 lb /lb of dry air		0.23617435	lbs/lb of "as fired" fuel			
Lma =	moisture in air * (enthalpy of water vapor leaving air heater -						
		enthalpy of vapor at mill inlet temp)					
7. Heat loss due to formation of carbon monoxide					=	0.02	
Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel						
8. Heat loss due to radiation		10 exp (0.62-0.42log Q)			=	1.69	
Total Losses (%)					=	16.31	%
HEAT CREDITS							
1. Heat supplied by duct burner to entering air					-103.06	Btu/lb of "as Fired" Fuel	
2. Heat supplied by mill to primary (transport) air					0.00	Btu/lb of "as Fired" Fuel	
Boiler Efficiency (%)=						83.61	%
Combustion Air Flow (lb,hr)=						6765	lb/h

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/9/95am				
3		19.0lb/min coal; Prim. 0%, Sec. 0%, Tert. 100%;Coal gun 42.25",Gas Gun -8.5; Xfer 340 acfm; O2 3.5%				
4	Pressures and Temperatures		Steam Data			
5						
6	Drum Steam Pressure (Psig)	190.9	Enthalpy of Sat. Liq. (Btu/lb)	346.4		
7	Feed Water Temperature (°F)	217.9	Enthalpy of Feed Water (Btu/lb)	186.2	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	100.0	Steam Production Rate (PPH)	13,466.4		
9	Gas Temp.Leaving Boiler (°F)	587.9	Blow down Rate (PPH)	3,026.9		
10	Gas Temp. Leaving Air Heater (°F)	403.1	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,243.1	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	177.2	Enthalpy of water at fuel inlet temp. (Btu/lb)	57.6	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	427.2	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,100.7	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	404.2	Calorimeter Temperature (°F)	312.5		
14	Mill Inlet Temperature (°F)	89.6				
15	Mill air flow rate (lb/h)	1,623.5	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner Inlet temperature (°F)	187.9	Coal H.H. Value (Btu/lb)	14414	Gas Cal. Value (Btu/lb)	23346
17	FUEL DATA		Coal Moisture Content (%)	4.45		
18	Proximate Analysis					
19	Moisture (Wt%)	1.99	**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)	31.32				
21	Fixed Carbon (Wt%)	64.11				
22	Ash (Wt%)	4.92	Carbon	82.32	Methane	95.54
23			Hydrogen	5.29	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14414	Nitrogen	1.41	Propane	0
25			Sulfur	0.77	Butane	0.43
26			Oxygen	5.64	Hydrogen Sulfide	0
27			Ash	4.57	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	Flue Gas Analysis				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.46				
33	Carbon Dioxide (%)	15.81	Ash in Dry Char/Refuse	47.55		
34	Carbon Monoxide (PPM)	238.04	TOTAL CARBON CONVERSION	94.10		
35	Sulfur Dioxide (PPM)	512.04	COAL CARBON CONVERSION	94.10		
36	Oxides of Nitrogen (PPM)	370.93				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	8/9/95am				
47						
48						
49						
50						
51	**Boiler Operating Conditions**					
52						
53						
54	Total Firing Rate		16.43200755	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	**Excess air used (%)**		19.31	%		
57						
58	**Actual mass of products of combustion**	=	16053.15136	lb/lb of "as fired" fuel		
59						
60	**Theoretical flue gas composition**	%				
61	Carbon Dioxide	14.42				
62	Water vapor	6.31				
63	Oxygen	3.26				
64	Nitrogen	75.96				
65	Sulfur Dioxide (ppm)	506				
66	Total	100.00				
67	**Boiler Efficiency Details**					
68				%		
69	1. Heat loss due to Dry gas (%)			6.24		
70	2. Heat loss due to unburned carbon			4.67		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.37		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.71		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.08		
76	8. Heat loss due to radiation			1.29		
77	9. Heat loss due to steam drum blowdown			0.00		
78	**Total Losses**			16.51		
79	**Heat Credits**					
80	1. Heat supplied by duct burner to entering air			-72.58	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			34.39	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			83.44		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16431960		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	78.66		Carbon	78.66			
25	Gas Heat Input (Btu/h)	0		Hydrogen	5.05		Hydrogen	5.05			
26	Total Firing Rate	16431960		Nitrogen	1.35		Nitrogen	1.35			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.74		Sulfur	0.74			
28	Gas Firing Rate (lb/h)	0		Oxygen	5.39		Oxygen	5.39			
29	Gas Support (% of Heat)	0.00		Ash	4.37		Ash	4.37			
30	Fraction of coal	1		Moisture	4.45		Moisture	4.45			
31	Fraction of GAS	0		Total	100.00		Total	100.00			
32											
33				HHV	14414		HHV	14414			
34				Dry ash%	4.57		Dry Ash	4.57			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.0655473	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.01263649	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00022992	moles							
49											
50	Oxygen required= Sum of the 3		0.0784137	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00168407								
52	Net Oxygen required =		0.07672964	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36537922	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			19.31					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.43592685					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		13.0647276					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			13.0817117					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					14.0817117	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		16053.1514	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4										
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.0655473	Wet Flue Gas Compositon (%) 14.42			Dry Flue Gas Comp. (%) 15.39		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02868876	6.31			0.00		
8	Oxygen			0.014815	3.26			3.48		
9	Nitrogen			0.34530942	75.96			81.08		
10	Sulfur Dioxide			0.00022992	0.05057678			0.05		
11	Total			0.4545904	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		11.94631506	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.24			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	4.67			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.37			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.71			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.61	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.66	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16452349	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.08			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.29			
64										
65										
66										
67										
68	Total Losses (%)						16.51	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-72.58	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					34.39	Btu/lb of "as Fired" Fuel			
73										
74	Boiler Efficiency (%)=						83.44	%		
75										
76										
77	Combustion Air Flow (lb,hr)=						14615	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/9/95pm				
3		19.0lb/min coal; Prim. 100%, Sec. 0%, Tert. 0%;Coal gun 42.25",Gas Gun -8.5; Xfer 325 acfm; O2 2.7%				
4	Pressures and Temperatures					
5			Steam Data			
6	Drum Steam Pressure (Psig)	185.7	Enthalpy of Sat. Liq. (Btu/lb)	344.2		
7	Feed Water Temperature (°F)	218.6	Enthalpy of Feed Water (Btu/lb)	186.8	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	100.0	Steam Production Rate (PPH)	14,367.0		
9	Gas Temp.Leaving Boiler (°F)	606.8	Blow down Rate (PPH)	2,985.5		
10	Gas Temp. Leaving Air Heater (°F)	414.1	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,248.2	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	182.5	Enthalpy of water at fuel inlet temp. (Btu/lb)	66.1	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	436.0	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,104.5	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	415.2	Calorimeter Temperature (°F)	312.3		
14	Mill Inlet Temperature (°F)	98.1				
15	Mill air flow rate (lb/h)	1,525.6	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner Inlet temperature (°F)	199.2	Coal H.H. Value (Btu/lb)	14414	Gas Cal. Value (Btu/lb)	23346
17	FUEL DATA		Coal Moisture Content (%)	4.45		
18	Proximate Analysis					
19	Moisture (Wt%)	4.61	Ultimate Analysis (Wt%. d.b)		Gas Analysis (Dry Vol%)	
20	Volatile Matter (Wt%)	31.32				
21	Fixed Carbon (Wt%)	64.11				
22	Ash (Wt%)	4.45	Carbon	82.32	Methane	95.54
23			Hydrogen	5.29	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14414	Nitrogen	1.41	Propane	0
25			Sulfur	0.77	Butane	0.43
26			Oxygen	5.64	Hydrogen Sulfide	0
27		—	Ash	4.57	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	Flue Gas Analysis				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	2.69				
33	Carbon Dioxide (%)	16.46	Ash in Dry Char/Refuse	59.7		
34	Carbon Monoxide (PPM)	149.04	TOTAL CARBON CONVERSION	96.94		
35	Sulfur Dioxide (PPM)	551.93	COAL CARBON CONVERSION	96.94		
36	Oxides of Nitrogen (PPM)	684.35				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	8/9/95pm				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		16.4320197	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		14.38	%		
57						
58	Actual mass of products of combustion =		15436.85043	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	15.02				
62	Water vapor	6.56				
63	Oxygen	2.53				
64	Nitrogen	75.84				
65	Sulfur Dioxide (ppm)	527				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			6.24		
70	2. Heat loss due to unburned carbon			2.42		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.36		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.70		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.05		
76	8. Heat loss due to radiation			1.29		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			14.22		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-62.61	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			33.24	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			85.75		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1											
2				**Boiler Performance Calculations**							
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)			Density at 60°F (lb/cu.ft)	lbs in each Cu.ft of gas		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
6	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
7	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
8	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
9	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
10	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
11	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
12	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
13	**Total**	100									
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16431960		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	78.66		Carbon	78.66			
25	Gas Heat Input (Btu/h)	0		Hydrogen	5.05		Hydrogen	5.05			
26	Total Firing Rate	16431960		Nitrogen	1.35		Nitrogen	1.35			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.74		Sulfur	0.74			
28	Gas Firing Rate (lb/h)	0		Oxygen	5.39		Oxygen	5.39			
29	Gas Support (% of Heat)	0.00		Ash	4.37		Ash	4.37			
30	Fraction of coal	1		Moisture	4.45		Moisture	4.45			
31	Fraction of GAS	0		Total	100.00		Total	100.00			
32											
33				HHV	14414		HHV	14414			
34				Dry ash%	4.57		Dry Ash	4.57			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.0655473	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.01263649	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00022992	moles							
49											
50	Oxygen required= Sum of the 3		0.0784137	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00168407								
52	Net Oxygen required =		0.07672964	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36537922	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2)=			14.38					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.41791173					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		12.5248146					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			12.5410969					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					13.5410969	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		15436.8504	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4										
5	Carbon Dioxide	(=moles of carbon /lb of fuel)			Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
6	Water	(moles of water in fuel +moles		0.0655473	15.02			16.07		
7		of water in combustion air)								
8	Oxygen			0.02864977	6.56			0.00		
9	Nitrogen			0.01103183	2.53			2.70		
10	Sulfur Dioxide			0.33107748	75.84			81.17		
11	Total			0.00022992	0.05266852			0.06		
12				0.43653629	100.00			100.00		
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		11.85622748	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.24			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	2.42			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.36			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.70			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.61	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.13	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.1577244	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.05			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.29			
64										
65										
66										
67										
68	Total Losses (%)						14.22	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-62.61	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					33.24	Btu/lb of "as Fired" Fuel			
73										
74	**Boiler Efficiency (%)=**						85.75	%		
75										
76										
77	**Combustion Air Flow (lb,hr)=**						14011	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/23/95				
3		19.0lb/min coal; Prim. 100%, Sec. 70%, Tert. 50%;Coal gun ",Gas Gun 32"; Xfer 360 acfm; O2 4.0%				
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	186.7	Enthalpy of Sat. Liq. (Btu/lb)	344.7		
7	Feed Water Temperature (°F)	207.6	Enthalpy of Feed Water (Btu/lb)	175.7	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	13,467.2		
9	Gas Temp.Leaving Boiler (°F)	549.4	Blow down Rate (PPH)	2,993.9		
10	Gas Temp. Leaving Air Heater (°F)	377.6	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,231.4	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	174.7	Enthalpy of water at fuel inlet temp. (Btu/lb)	49.6	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	404.2	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,097.1	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	382.1	Calorimeter Temperature (°F)	301.7		
14	Mill Inlet Temperature (°F)	81.6				
15	Mill air flow rate (lb/h)	1,691.2	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner Inlet temperature (°F)	185.1	Coal H.H. Value (Btu/lb)	14444	Gas Cal. Value (Btu/lb)	23346
17	**FUEL DATA**		Coal Moisture Content (%)	4.63		
18	**Proximate Analysis**					
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)	30.82				
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	4.36	Carbon	82.41	Methane	95.54
23			Hydrogen	5.04	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14444	Nitrogen	1.4	Propane	0
25			Sulfur	0.81	Butane	0.43
26			Oxygen	5.98	Hydrogen Sulfide	0
27			Ash	4.36	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.39				
33	Carbon Dioxide (%)	15.60	Ash in Dry Char/Refuse	30.81		
34	Carbon Monoxide (PPM)	258.21	TOTAL CARBON CONVERSION	89.16		
35	Sulfur Dioxide (PPM)	582.84	COAL CARBON CONVERSION	89.16		
36	Oxides of Nitrogen (PPM)	280.76				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	23-Aug				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		16.46619081	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		18.75	%		
57						
58	Actual mass of products of combustion	=	15836.41255	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	14.63				
62	Water vapor	6.15				
63	Oxygen	3.18				
64	Nitrogen	75.99				
65	Sulfur Dioxide (ppm)	539				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			5.63		
70	2. Heat loss due to unburned carbon			8.55		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.38		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.51		
74	6. Heat loss due to moisture in combustion air			0.15		
75	7. Heat loss due to formation of carbon monoxide			0.08		
76	8. Heat loss due to radiation			1.29		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			19.59		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-68.60	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			37.70	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			80.36		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1											
2				**Boiler Performance Calculations**							
3											
4											
5	Fuel Gas Composition (Dry. Vol%)	Conversion of Gas Composition from Volume % to Wt%									
6	Methane	95.54	Density at 60°F (lb/cu.ft)	0.04246	lbs in each Cu.ft of gas 0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16466160									
24				As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
25	Gas Heat Input (Btu/h)	0		Carbon	78.59		Carbon	78.59			
26	Total Firing Rate	16466160		Hydrogen	4.81		Hydrogen	4.81			
27	Gas Calorific Value (Btu/lb)	23346		Nitrogen	1.34		Nitrogen	1.34			
28	Gas Firing Rate (lb/h)	0		Sulfur	0.77		Sulfur	0.77			
29	Gas Support (% of Heat)	0.00		Oxygen	5.70		Oxygen	5.70			
30	Fraction of coal	1		Ash	4.16		Ash	4.16			
31	Fraction of GAS	0		Moisture	4.63		Moisture	4.63			
32				Total	100.00		Total	100.00			
33											
34				HHV	14444		HHV	14444			
35				Dry ash%	4.36		Dry Ash	4.36			
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06549535	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.01201662	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00024141	moles							
49											
50	Oxygen required= Sum of the 3		0.07775337	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00178223								
52	Net Oxygen required =		0.07597115	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54											
55			0.36176736	moles/lb of as fired fuel							
56	Calculation of Products of combustion										
57											
58	Excess air used (%)										
59			= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			18.75					
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.42959135					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		12.8748526					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013								
65						12.89159					
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					13.89159	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69			=								
70					15836.4125	lb of flue gas					
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06549535	14.63			15.58		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02753531	6.15			0.00		
8	Oxygen			0.01424304	3.18			3.39		
9	Nitrogen			0.34030437	75.99			80.97		
10	Sulfur Dioxide			0.00024141	0.05390684			0.06		
11	Total			0.44781948	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		11.44711808	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	5.63			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	8.55			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.38			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.51			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air									
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel					=	0.15			
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (%_sulfur))/HHV=							
49										
50		=	10.50	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.47	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16213203	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.08			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.29			
64										
65										
66										
67										
68	Total Losses (%)						19.59	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-68.60	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					37.70	Btu/lb of "as Fired" Fuel			
73										
74	**Boiler Efficiency (%)=**						80.36	%		
75										
76										
77	**Combustion Air Flow (lb,hr)=**						14403	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/24/95				
3						
4	**Pressures and Temperatures**	19.0lb/min coal; Prim. 100%, Sec. 100%, Tert. 50%;Coal gun -10.5",Gas Gun -9"; Xfer 380 acfm; O2 3.75%				
5			**Steam Data**			
6	Drum Steam Pressure (Psig)	183.44	Enthalpy of Sat. Liq. (Btu/lb)	343.3		
7	Feed Water Temperature (°F)	206.55	Enthalpy of Feed Water (Btu/lb)	174.7	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	14416.55		
9	Gas Temp.Leaving Boiler (°F)	539.36	Blow down Rate (PPH)	2967.46		
10	Gas Temp. Leaving Air Heater (°F)	377.94	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,231.6	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	171.10	Enthalpy of water at fuel inlet temp. (Btu/lb)	54.3	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	394.80	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,099.2	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	376.58	Calorimeter Temperature (°F)	300.9		
14	Mill Inlet Temperature (°F)	86.25				
15	Mill air flow rate (lb/h)	1,711	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner Inlet temperature (°F)	183.20	Coal H.H. Value (Btu/lb)	14444	Gas Cal. Value (Btu/lb)	23346
17	**FUEL DATA**		Coal Moisture Content (%)	3.67		
18	**Proximate Analysis**					
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)	30.82				
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	4.43	Carbon	82.41	Methane	95.54
23			Hydrogen	5.04	Ethane	2.48
24	HHV (Btu/lb, d.b)	14444	Nitrogen	1.4	Propane	0
25			Sulfur	0.81	Butane	0.43
26			Oxygen	5.98	Hydrogen Sulfide	0
27			Ash	4.36	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.76				
33	Carbon Dioxide (%)	15.03	Ash in Dry Char/Refuse	49.94		
34	Carbon Monoxide (PPM)	146.15	TOTAL CARBON CONVERSION	95.30		
35	Sulfur Dioxide (PPM)	484.88	COAL CARBON CONVERSION	95.30		
36	Oxides of Nitrogen (PPM)	442.91				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	24-Aug				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		16.46620994	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		21.21	%		
57						
58	Actual mass of products of combustion	=	16291.52447	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	14.36				
62	Water vapor	5.92				
63	Oxygen	3.53				
64	Nitrogen	76.14				
65	Sulfur Dioxide (ppm)	529				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			6.21		
70	2. Heat loss due to unburned carbon			3.75		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.30		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.54		
74	6. Heat loss due to moisture in combustion air			0.15		
75	7. Heat loss due to formation of carbon monoxide			0.05		
76	8. Heat loss due to radiation			1.29		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			15.28		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-58.27	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			35.72	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			84.70		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)			Density at 60°F (lb/cu.ft)	lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14				Density of N. gas (lb/cu.ft) =	0.04439078						
15											
16											
17											
18											
19		Determination of Percent Gas Support									
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16466160									
24				As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
25	Gas Heat Input (Btu/h)	0		Carbon	79.39		Carbon	79.39			
26	Total Firing Rate	16466160		Hydrogen	4.86		Hydrogen	4.86			
27	Gas Calorific Value (Btu/lb)	23346		Nitrogen	1.35		Nitrogen	1.35			
28	Gas Firing Rate (lb/h)	0		Sulfur	0.78		Sulfur	0.78			
29	Gas Support (% of Heat)	0.00		Oxygen	5.76		Oxygen	5.76			
30	Fraction of coal	1		Ash	4.20		Ash	4.20			
31	Fraction of GAS	0		Moisture	3.67		Moisture	3.67			
32				Total	100.00		Total	100.00			
33											
34				HHV	14444		HHV	14444			
35				Dry ash%	4.36		Dry Ash	4.36			
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45											
46	Carbon= %C/(100*12) *1mole =		Theoretical Oxygen Requirement								
47	Hydrogen= %H/(100*2)*0.5 mole =		0.06615463	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.01213758	moles							
49			0.00024384	moles							
50	Oxygen required= Sum of the 3		0.07853604	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00180017								
52	Net Oxygen required =		0.07673588	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36540893	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)										
59			= 100(O2-CO/2)/(0.264*N2-(O2-CO/2)=			21.21					
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =										
61	Dry air in lbs/lb of "as fired" fuel					0.44289474					
62				= moles of air*29.97 =		13.2735553					
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013								
65						13.2908109					
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67											
68	Actual weight of products =				14.2908109	lb/lb of fuel					
69			lbs of fuel burned * Wt of Products/lb of fuel								
70			=		16291.5245	lb of flue gas					
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06615463	14.36			15.26		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02727269	5.92			0.00		
8	Oxygen			0.01627202	3.53			3.75		
9	Nitrogen			0.35081405	76.14			80.93		
10	Sulfur Dioxide			0.00024384	0.05292056			0.06		
11	Total			0.46075723	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.80678049	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.21			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	3.75			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.30			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.54			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmlh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.15			
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.61	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.86	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16715286	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.05			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.29			
64										
65										
66										
67										
68	Total Losses (%)						15.28	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air									
72	2. Heat supplied by mill to primary (transport) air					-58.27	Btu/lb of "as Fired" Fuel			
73						35.72	Btu/lb of "as Fired" Fuel			
74	Boiler Efficiency (%)=						84.70	%		
75										
76										
77	Combustion Air Flow (lb,hr)=						14849	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/25/95				
3		19.0lb/min coal; Prim. 0%, Sec. 0%, Tert. 50%;Coal gun -11",Gas Gun -9"; Xfer 355 acfm; O2 3.5%				
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	187.4	Enthalpy of Sat. Liq. (Btu/lb)			
7	Feed Water Temperature (°F)	207.2	Enthalpy of Feed Water (Btu/lb)	344.9		
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	175.3	(Sat. liquid @ Feed water temp.)	
9	Gas Temp.Leaving Boiler (°F)	594.2	Blow down Rate (PPH)	14,378.5		
10	Gas Temp. Leaving Air Heater (°F)	399.7	Enthalpy of water vapor at Glvg Temp (Btu/lb)	2,999.0		
11	Air Temp Entering Air Heater (°F)	165.9	Enthalpy of water at fuel inlet temp. (Btu/lb)	1,241.6	(Sup. steam @ 1psia&gas lvg temp)	
12	Air temp leaving Air Pre Heater (°F)	421.1	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	52.0	(Sat. liq. @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	398.8	Calorimeter Temperature (°F)	1,096.3	(Sat. vapor @ mill inlet temp.)	
14	Mill Inlet Temperature (°F)	83.9		301.0		
15	Mill air flow rate (lb/h)	1,710.5	Coal Firing Rate (lb/h)			
16	Burner Inlet temperature (°F)	184.1	Coal H.H. Value (Btu/lb)	1140	Gas Firing Rate (lb/h)	0
17	**FUEL DATA**		Coal Moisture Content (%)	14444	Gas Cal. Value (Btu/lb)	23346
18	**Proximate Analysis**			3.89		
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**			
20	Volatile Matter (Wt%)	30.82			**Gas Analysis (Dry Vol%)**	
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	4.36	Carbon			
23			Hydrogen	82.41	Methane	95.54
24	**HHV (Btu/lb,. d.b)**	14444	Nitrogen	5.04	Ethane	2.48
25			Sulfur	1.4	Propane	0
26			Oxygen	0.81	Butane	0.43
27			Ash	5.98	Hydrogen Sulfide	0
28			Total	4.36	Carbon Dioxide	1.55
29				100	Nitrogen	
30	**Flue Gas Analysis**				Others	
31					Total	100
32	Oxygen (%)	3.31			Moisture (wt%)	0.05
33	Carbon Dioxide (%)	15.30	Ash in Dry Char/Refuse			
34	Carbon Monoxide (PPM)	178.04	TOTAL CARBON CONVERSION	43.89		
35	Sulfur Dioxide (PPM)	528.92	COAL CARBON CONVERSION	94.25		
36	Oxides of Nitrogen (PPM)	439.46		94.25		
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	25-Aug				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		16.46620389	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		18.16	%		
57						
58	Actual mass of products of combustion =		15876.54885	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	14.71				
62	Water vapor	6.09				
63	Oxygen	3.10				
64	Nitrogen	76.05				
65	Sulfur Dioxide (ppm)	542				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			6.52		
70	2. Heat loss due to unburned carbon			4.57		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.32		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.56		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.06		
76	8. Heat loss due to radiation			1.29		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			16.48		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-69.40	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			36.91	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			83.48		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1											
2				Boiler Performance Calculations							
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14											
15			Density of N. gas (lb/cu.ft) =		0.04439078						
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16466160									
24				As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
25	Gas Heat Input (Btu/h)	0		Carbon	79.20		Carbon	79.20			
26	Total Firing Rate	16466160		Hydrogen	4.84		Hydrogen	4.84			
27	Gas Calorific Value (Btu/lb)	23346		Nitrogen	1.35		Nitrogen	1.35			
28	Gas Firing Rate (lb/h)	0		Sulfur	0.78		Sulfur	0.78			
29	Gas Support (% of Heat)	0.00		Oxygen	5.75		Oxygen	5.75			
30	Fraction of coal	1		Ash	4.19		Ash	4.19			
31	Fraction of GAS	0		Moisture	3.89		Moisture	3.89			
32				Total	100.00		Total	100.00			
33											
34				HHV	14444		HHV	14444			
35				Dry ash%	4.36		Dry Ash	4.36			
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45											
46	Carbon= %C/(100*12) *1mole =		Theoretical Oxygen Requirement								
47	Hydrogen= %H/(100*2)*0.5 mole =		0.06600354	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.01210986	moles							
49			0.00024328	moles							
50	Oxygen required= Sum of the 3		0.07835668	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00179606								
52	Net Oxygen required =		0.07656063	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36457441	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=								
59						18.16					
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =										
61	Dry air in lbs/lb of "as fired" fuel					0.43076457					
62				= moles of air*29.97 =		12.9100142					
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013								
65						12.9267972					
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67											
68	Actual weight of products =				13.9267972	lb/lb of fuel					
69			lbs of fuel burned * Wt of Products/lb of fuel								
70			=		15876.5489	lb of flue gas					
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06600354	14.71			15.66		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02731322	6.09			0.00		
8	Oxygen			0.01389993	3.10			3.30		
9	Nitrogen			0.34123122	76.05			80.98		
10	Sulfur Dioxide			0.00024328	0.05421957			0.06		
11	Total			0.4486912	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.42096983	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.52			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	4.57			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.32			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.56			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.58	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.51	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16257482	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.06			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.29			
64										
65										
66										
67										
68	Total Losses (%)						16.48	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-69.40	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					36.91	Btu/lb of "as Fired" Fuel			
73										
74	Boiler Efficiency (%)=						83.48	%		
75										
76										
77	Combustion Air Flow (lb,hr)=						14442	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/28/95				
3						
4	**Pressures and Temperatures**	19.0lb/min coal; Prim. 100%, Sec. 100%, Tert. 50%;Coal gun -10.5",Gas Gun -9"; Xfer 390 acfm; O2 3.75%				
5			**Steam Data**			
6	Drum Steam Pressure (Psig)	187.1	Enthalpy of Sat. Liq. (Btu/lb)	344.8		
7	Feed Water Temperature (°F)	205.9	Enthalpy of Feed Water (Btu/lb)	174.0	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	14,038.7		
9	Gas Temp.Leaving Boiler (°F)	562.3	Blow down Rate (PPH)	2,996.6		
10	Gas Temp. Leaving Air Heater (°F)	386.1	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,235.3	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	167.7	Enthalpy of water at fuel inlet temp. (Btu/lb)	51.8	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	405.7	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,096.3	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	382.9	Calorimeter Temperature (°F)	300.5		
14	Mill Inlet Temperature (°F)	83.8				
15	Mill air flow rate (lb/h)	1,852.5	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner inlet temperature (°F)	175.4	Coal H.H. Value (Btu/lb)	14490	Gas Cal. Value (Btu/lb)	23346
17	**FUEL DATA**		Coal Moisture Content (%)	4.5		
18	**Proximate Analysis**					
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**			
20	Volatile Matter (Wt%)	30.82			**Gas Analysis (Dry Vol%)**	
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	4.37	Carbon	82.78	Methane	95.54
23			Hydrogen	5.16	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14490	Nitrogen	1.41	Propane	0
25			Sulfur	0.85	Butane	0.43
26			Oxygen	5.49	Hydrogen Sulfide	0
27			Ash	4.31	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.51				
33	Carbon Dioxide (%)	15.35	Ash in Dry Char/Refuse	47.9		
34	Carbon Monoxide (PPM)	129.16	TOTAL CARBON CONVERSION	94.40		
35	Sulfur Dioxide (PPM)	474.10	COAL CARBON CONVERSION	94.40		
36	Oxides of Nitrogen (PPM)	384.70				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	28-Aug				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		16.5186479	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		19.52	%		
57						
58	Actual mass of products of combustion	=	16096.49797	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	14.46				
62	Water vapor	6.17				
63	Oxygen	3.29				
64	Nitrogen	76.02				
65	Sulfur Dioxide (ppm)	557				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			6.20		
70	2. Heat loss due to unburned carbon			4.43		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.37		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.60		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.04		
76	8. Heat loss due to radiation			1.28		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			16.08		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-72.09	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			36.56	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			83.88		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1				**Boiler Performance Calculations**							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
6	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
7	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
8	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
9	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
10	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
11	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
12	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
13	**Total**	100									
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16518600		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	79.05		Carbon	79.05			
25	Gas Heat Input (Btu/h)	0		Hydrogen	4.93		Hydrogen	4.93			
26	Total Firing Rate	16518600		Nitrogen	1.35		Nitrogen	1.35			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.81		Sulfur	0.81			
28	Gas Firing Rate (lb/h)	0		Oxygen	5.24		Oxygen	5.24			
29	Gas Support (% of Heat)	0.00		Ash	4.12		Ash	4.12			
30	Fraction of coal	1		Moisture	4.5		Moisture	4.50			
31	Fraction of GAS	0		Total	100.00		Total	100.00			
32											
33				HHV	14490		HHV	14490			
34				Dry ash%	4.31		Dry Ash	4.31			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06587908	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.0123195	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00025367	moles							
49											
50	Oxygen required= Sum of the 3		0.07845226	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00163842								
52	Net Oxygen required =		0.07681383	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36578016	moles/lb of as fired fuel							
55											
56	**Calculation of Products of combustion**										
57											
58	**Excess air used (%)**		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2)=			19.52					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.43719391					
61	**Dry air in lbs/lb of "as fired" fuel**			= moles of air*29.97 =		13.1027016					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			13.1197351					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					14.1197351	lb/lb of fuel					
68	**Actual weight of products =**		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		16096.498	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas	Compositon (%)		Dry Flue Gas	Comp. (%)	
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06587908	14.46			15.41		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02808531	6.17			0.00		
8	Oxygen			0.01499689	3.29			3.51		
9	Nitrogen			0.3463104	76.02			81.02		
10	Sulfur Dioxide			0.00025367	0.05568776			0.06		
11	Total			0.45552535	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.38399157	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.20			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	4.43			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.37			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.60			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.62	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.69	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16500152	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.04			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.28			
64										
65										
66										
67										
68	Total Losses (%)						16.08	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-72.09	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					36.56	Btu/lb of "as Fired" Fuel			
73										
74	**Boiler Efficiency (%)=**						83.88	%		
75										
76										
77	**Combustion Air Flow (lb,hr)=**						14657	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/29/95				
3		19.0lb/min coal; Prim. 0%, Sec. 0%, Tert. 100%;Coal gun -10.5",Gas Gun -9"; Xfer 400 acfm; O2 3.75%				
4	Pressures and Temperatures		Steam Data			
5						
6	Drum Steam Pressure (Psig)	183.3	Enthalpy of Sat. Liq. (Btu/lb)	343.2		
7	Feed Water Temperature (°F)	206.3	Enthalpy of Feed Water (Btu/lb)	174.5	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	13,938.2		
9	Gas Temp.Leaving Boiler (°F)	560.8	Blow down Rate (PPH)	2,966.2		
10	Gas Temp. Leaving Air Heater (°F)	388.9	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,236.6	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	177.2	Enthalpy of water at fuel inlet temp. (Btu/lb)	55.6	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	406.3	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,096.3	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	387.1	Calorimeter Temperature (°F)	301.4		
14	Mill Inlet Temperature (°F)	87.6				
15	Mill air flow rate (lb/h)	1,685.2	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner Inlet temperature (°F)	180.3	Coal H.H. Value (Btu/lb)	14490	Gas Cal. Value (Btu/lb)	23346
17	FUEL DATA		Coal Moisture Content (%)	4.51		
18	Proximate Analysis					
19	Moisture (Wt%)	1.79	Ultimate Analysis (Wt%. d.b)		Gas Analysis (Dry Vol%)	
20	Volatile Matter (Wt%)	30.94				
21	Fixed Carbon (Wt%)	64.75				
22	Ash (Wt%)	4.26	Carbon	82.78	Methane	95.54
23			Hydrogen	5.16	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14490	Nitrogen	1.41	Propane	0
25			Sulfur	0.85	Butane	0.43
26			Oxygen	5.49	Hydrogen Sulfide	0
27			Ash	4.31	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	Flue Gas Analysis				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.55				
33	Carbon Dioxide (%)	15.40	Ash in Dry Char/Refuse	50.49		
34	Carbon Monoxide (PPM)	165.58	TOTAL CARBON CONVERSION	95.60		
35	Sulfur Dioxide (PPM)	511.21	COAL CARBON CONVERSION	95.60		
36	Oxides of Nitrogen (PPM)	361.43				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	29-Aug				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		16.51865049	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		19.83	%		
57						
58	Actual mass of products of combustion	=	16133.72495	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	14.43				
62	Water vapor	6.15				
63	Oxygen	3.34				
64	Nitrogen	76.03				
65	Sulfur Dioxide (ppm)	555				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			6.24		
70	2. Heat loss due to unburned carbon			3.48		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.37		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.59		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.06		
76	8. Heat loss due to radiation			1.28		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			15.18		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-60.56	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			33.65	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			84.79		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1				**Boiler Performance Calculations**							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)			Density at 60°F (lb/cu.ft)	lbs in each Cu.ft of gas		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
6	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
7	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
8	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
9	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
10	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
11	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
12	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
13	**Total**	100									
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16518600		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	79.05		Carbon	79.05			
25	Gas Heat Input (Btu/h)	0		Hydrogen	4.93		Hydrogen	4.93			
26	Total Firing Rate	16518600		Nitrogen	1.35		Nitrogen	1.35			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.81		Sulfur	0.81			
28	Gas Firing Rate (lb/h)	0		Oxygen	5.24		Oxygen	5.24			
29	Gas Support (% of Heat)	0.00		Ash	4.12		Ash	4.12			
30	Fraction of coal	1		Moisture	4.51		Moisture	4.51			
31	Fraction of GAS	0		Total	100.00		Total	100.00			
32											
33				HHV	14490		HHV	14490			
34				Dry ash%	4.31		Dry Ash	4.31			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06587219	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.01231821	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00025365	moles							
49											
50	Oxygen required= Sum of the 3		0.07844404	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00163825								
52	Net Oxygen required =		0.07680579	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36574186	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			19.83					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.4382821					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		13.1353144					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80"F)=										
64		=	lbs of dry air * 1.0013			13.1523903					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					14.1523903	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		16133.7249	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas	Compositon (%)		Dry Flue Gas	Comp. (%)	
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06587219	14.43			15.37		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02809064	6.15			0.00		
8	Oxygen			0.01523345	3.34			3.55		
9	Nitrogen			0.34717007	76.03			81.01		
10	Sulfur Dioxide			0.00025365	0.05554845			0.06		
11	Total			0.45661998	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.50466265	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.24			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	3.48			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.37			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.59			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.62	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.72	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16541221	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.06			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.28			
64										
65										
66										
67										
68	Total Losses (%)						15.18	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-60.56	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					33.65	Btu/lb of "as Fired" Fuel			
73										
74	**Boiler Efficiency (%)=**						84.79	%		
75										
76										
77	**Combustion Air Flow (lb,hr)=**						14694	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/30/95				
3		19.0lb/min coal; Prim. 100%, Sec. 100%, Tert. 50%;Coal gun -10.5",Gas Gun -9"; Xfer 390 acfm; O2 3.75%				
4	Pressures and Temperatures		Steam Data			
5						
6	Drum Steam Pressure (Psig)	186.1	Enthalpy of Sat. Liq. (Btu/lb)	344.4		
7	Feed Water Temperature (°F)	207.6	Enthalpy of Feed Water (Btu/lb)	175.7	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.4	Steam Production Rate (PPH)	14,138.7		
9	Gas Temp.Leaving Boiler (°F)	565.5	Blow down Rate (PPH)	2,988.5		
10	Gas Temp. Leaving Air Heater (°F)	389.8	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,237.0	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	173.0	Enthalpy of water at fuel inlet temp. (Btu/lb)	59.1	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	405.6	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,096.3	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	385.1	Calorimeter Temperature (°F)	301.8		
14	Mill Inlet Temperature (°F)	91.1				
15	Mill air flow rate (lb/h)	1,838.0	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner inlet temperature (°F)	179.9	Coal H.H. Value (Btu/lb)	14490	Gas Cal. Value (Btu/lb)	23346
17	FUEL DATA		Coal Moisture Content (%)	4.35		
18	Proximate Analysis					
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)	30.82				
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	4.37	Carbon	82.78	Methane	95.54
23			Hydrogen	5.16	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14490	Nitrogen	1.41	Propane	0
25			Sulfur	0.85	Butane	0.43
26			Oxygen	5.49	Hydrogen Sulfide	0
27			Ash	4.31	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	Flue Gas Analysis				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.80				
33	Carbon Dioxide (%)	15.30	Ash in Dry Char/Refuse	53.13		
34	Carbon Monoxide (PPM)	113.54	TOTAL CARBON CONVERSION	95.90		
35	Sulfur Dioxide (PPM)	537.82	COAL CARBON CONVERSION	95.90		
36	Oxides of Nitrogen (PPM)	324.73				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	30-Aug				
47						
48						
49						
50						
51	**Boiler Operating Conditions**					
52						
53						
54	Total Firing Rate		16.51865313	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		21.60	%		
57						
58	**Actual mass of products of combustion**	=	16380.19131	lb/lb of "as fired" fuel		
59						
60	**Theoretical flue gas composition**	%				
61	Carbon Dioxide	14.23				
62	Water vapor	6.05				
63	Oxygen	3.58				
64	Nitrogen	76.08				
65	Sulfur Dioxide (ppm)	548				
66	Total	100.00				
67	**Boiler Efficiency Details**					
68				%		
69	1. Heat loss due to Dry gas (%)			6.26		
70	2. Heat loss due to unburned carbon			3.25		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.35		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.59		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.04		
76	8. Heat loss due to radiation			1.28		
77	9. Heat loss due to steam drum blowdown			0.00		
78	**Total Losses**			14.93		
79	**Heat Credits**					
80	1. Heat supplied by duct burner to entering air			-66.12	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			35.14	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			85.04		
84						
85						

	G	H	I	J	K	L	M	N	O	P	Q
1				**Boiler Performance Calculations**							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16518600									
24				As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
25	Gas Heat Input (Btu/h)	0		Carbon	79.18		Carbon	79.18			
26	Total Firing Rate	16518600		Hydrogen	4.94		Hydrogen	4.94			
27	Gas Calorific Value (Btu/lb)	23346		Nitrogen	1.35		Nitrogen	1.35			
28	Gas Firing Rate (lb/h)	0		Sulfur	0.81		Sulfur	0.81			
29	Gas Support (% of Heat)	0.00		Oxygen	5.25		Oxygen	5.25			
30	Fraction of coal	1		Ash	4.12		Ash	4.12			
31	Fraction of GAS	0		Moisture	4.35		Moisture	4.35			
32				Total	100.00		Total	100.00			
33											
34				HHV	14490		HHV	14490			
35				Dry ash%	4.31		Dry Ash	4.31			
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45											
46	Carbon= %C/(100*12) *1mole =		Theoretical Oxygen Requirement								
47	Hydrogen= %H/(100*2)*0.5 mole =		0.06598256	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.01233885	moles							
49			0.00025407	moles							
50	Oxygen required= Sum of the 3		0.07857548	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.001641								
52	Net Oxygen required =		0.07693448	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.36635468	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			21.60					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.44548656					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		13.3512323					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			13.3685889					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					14.3685889	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		16380.1913	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06598256	14.23			15.14		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02805862	6.05			0.00		
8	Oxygen			0.01661769	3.58			3.81		
9	Nitrogen			0.35286159	76.08			80.98		
10	Sulfur Dioxide			0.00025407	0.05478315			0.06		
11	Total			0.46377454	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.64431686	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.26			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	3.25			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.35			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.59			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmlh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired' fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.64	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		12.93	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16813125	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.04			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.28			
64										
65										
66										
67										
68	Total Losses (%)						14.93	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-66.12	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					35.14	Btu/lb of "as Fired" Fuel			
73										
74	Boiler Efficiency (%)=						85.04	%		
75										
76										
77	Combustion Air Flow (lb,hr)=						14935	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	8/31/95				
3		19.0lb/min coal; Prim. 100%, Sec. 100%, Tert. 50%;Coal gun -10.5",Gas Gun -9"; Xfer 390 acfm; O2 3.5%				
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	186.0	Enthalpy of Sat. Liq. (Btu/lb)	344.4		
7	Feed Water Temperature (°F)	207.4	Enthalpy of Feed Water (Btu/lb)	175.5	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	13,601.1		
9	Gas Temp.Leaving Boiler (°F)	570.9	Blow down Rate (PPH)	2,988.3		
10	Gas Temp. Leaving Air Heater (°F)	390.8	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,237.5	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	175.2	Enthalpy of water at fuel inlet temp. (Btu/lb)	51.1	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	411.4	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,096.3	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	388.6	Calorimeter Temperature (°F)	301.6		
14	Mill Inlet Temperature (°F)	83.1				
15	Mill air flow rate (lb/h)	1,870.8	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner inlet temperature (°F)	172.6	Coal H.H. Value (Btu/lb)	14490	Gas Cal. Value (Btu/lb)	23346
17	**FUEL DATA**		Coal Moisture Content (%)	1.79		
18	**Proximate Analysis**					
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**			
20	Volatile Matter (Wt%)	30.82			**Gas Analysis (Dry Vol%)**	
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	4.56	Carbon	82.78	Methane	95.54
23			Hydrogen	5.16	Ethane	2.48
24	HHV (Btu/lb,. d.b)	14490	Nitrogen	1.41	Propane	0
25			Sulfur	0.85	Butane	0.43
26			Oxygen	5.49	Hydrogen Sulfide	0
27			Ash	4.31	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.45				
33	Carbon Dioxide (%)	15.57	Ash in Dry Char/Refuse	50.37		
34	Carbon Monoxide (PPM)	118.35	TOTAL CARBON CONVERSION	95.29		
35	Sulfur Dioxide (PPM)	477.95	COAL CARBON CONVERSION	95.29		
36	Oxides of Nitrogen (PPM)	340.75				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	31-Aug				
47						
48						
49						
50						
51	**Boiler Operating Conditions**					
52						
53						
54	Total Firing Rate		16.51865037	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	**Excess air used (%)**		19.19	%		
57						
58	**Actual mass of products of combustion**	=	16477.64683	lb/lb of "as fired" fuel		
59						
60	**Theoretical flue gas composition**	%				
61	Carbon Dioxide	14.55				
62	Water vapor	5.86				
63	Oxygen	3.26				
64	Nitrogen	76.27				
65	Sulfur Dioxide (ppm)	560				
66	Total	100.00				
67	**Boiler Efficiency Details**					
68				%		
69	1. Heat loss due to Dry gas (%)			6.47		
70	2. Heat loss due to unburned carbon			3.83		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.15		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.71		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.04		
76	8. Heat loss due to radiation			1.28		
77	9. Heat loss due to steam drum blowdown			0.00		
78	**Total Losses**			15.64		
79	**Heat Credits**					
80	1. Heat supplied by duct burner to entering air			-73.87	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			36.06	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			84.32		
84						
85						

Boiler Performance Calculations

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)		Density at 60°F (lb/cu.ft)		lbs in each Cu.ft of gas		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
6	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
7	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
8	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
9	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
10	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
11	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
12	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
13	Total	100									
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input(Btu/h)	16518600		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	81.30		Carbon	81.30			
25	Gas Heat Input (Btu/h)	0		Hydrogen	5.07		Hydrogen	5.07			
26	Total Firing Rate	16518600		Nitrogen	1.38		Nitrogen	1.38			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.83		Sulfur	0.83			
28	Gas Firing Rate (lb/h)	0		Oxygen	5.39		Oxygen	5.39			
29	Gas Support (% of Heat)	0.00		Ash	4.23		Ash	4.23			
30	Fraction of coal	1		Moisture	1.79		Moisture	1.79			
31	Fraction of GAS	0		Total	100.00		Total	100.00			
32											
33				HHV	14490		HHV	14490			
34				Dry ash%	4.31		Dry Ash	4.31			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45			Theoretical Oxygen Requirement								
46	Carbon= %C/(100*12) *1mole =		0.06774853	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.01266909	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00026087	moles							
49											
50	Oxygen required= Sum of the 3		0.08067849	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00168492								
52	Net Oxygen required =		0.07899358	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.37615989	moles/lb of as fired fuel							
55											
56	**Calculation of Products of combustion**										
57											
58	**Excess air used (%)**		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2))=			19.19					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.44833529					
61	**Dry air in lbs/lb of "as fired" fuel**			= moles of air*29.97 =		13.4366086					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64		=	lbs of dry air * 1.0013			13.4540762					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					14.4540762	lb/lb of fuel					
68	**Actual weight of products =**		lbs of fuel burned * Wt of Products/lb of fuel								
69			=		16477.6468	lb of flue gas					
70											
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06774853	14.55			15.46		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.02730305	5.86			0.00		
8	Oxygen			0.01515683	3.26			3.46		
9	Nitrogen			0.35511209	76.27			81.02		
10	Sulfur Dioxide			0.00026087	0.05603109			0.06		
11	Total			0.46558137	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.68718171	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.47			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	3.83			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.15			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.71			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.92	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		13.02	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.16920639	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.04			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.28			
64										
65										
66										
67										
68	Total Losses (%)						15.64	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-73.87	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					36.06	Btu/lb of "as Fired" Fuel			
73										
74	Boiler Efficiency (%)=						84.32	%		
75										
76										
77	Combustion Air Flow (lb,hr)=						15031	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										

	A	B	C	D	E	F
1	**Demonstration**		**Boiler Data**			
2	Date of Operation	9/5/95	PC 78% FIRE TEST			
3		18.3lb/min coal; Prim. 100%, Sec. 50%, Tert. 50%;Coal gun -10.5",Gas Gun -9"; Xfer 375 acfm; O2 3.5%				
4	**Pressures and Temperatures**		**Steam Data**			
5						
6	Drum Steam Pressure (Psig)	191.3	Enthalpy of Sat. Liq. (Btu/lb)	346.6		
7	Feed Water Temperature (°F)	198.7	Enthalpy of Feed Water (Btu/lb)	166.8	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	13,121.7		
9	Gas Temp.Leaving Boiler (°F)	571.3	Blow down Rate (PPH)	3,030.2		
10	Gas Temp. Leaving Air Heater (°F)	388.6	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,236.5	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	170.5	Enthalpy of water at fuel inlet temp. (Btu/lb)	47.8	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	402.8	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,096.3	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	376.9	Calorimeter Temperature (°F)	301.0		
14	Mill Inlet Temperature (°F)	79.7				
15	Mill air flow rate (lb/h)	1,775.1	Coal Firing Rate (lb/h)	1098	Gas Firing Rate (lb/h)	0
16	Burner inlet temperature (°F)	195.3	Coal H.H. Value (Btu/lb)	14533	Gas Cal. Value (Btu/lb)	23346
17	**FUEL DATA**		Coal Moisture Content (%)	0.75		
18	**Proximate Analysis**					
19	Moisture (Wt%)	1.87	**Ultimate Analysis (Wt%. d.b)**		**Gas Analysis (Dry Vol%)**	
20	Volatile Matter (Wt%)	30.82				
21	Fixed Carbon (Wt%)	64.82				
22	Ash (Wt%)	3.78	Carbon	82.05	Methane	95.54
23			Hydrogen	5.21	Ethane	2.48
24	**HHV (Btu/lb,. d.b)**	14533	Nitrogen	1.41	Propane	0
25			Sulfur	0.84	Butane	0.43
26			Oxygen	6.15	Hydrogen Sulfide	0
27			Ash	4.34	Carbon Dioxide	1.55
28			Total	100	Nitrogen	
29					Others	
30	**Flue Gas Analysis**				Total	100
31					Moisture (wt%)	0.05
32	Oxygen (%)	3.49				
33	Carbon Dioxide (%)	15.89	Ash in Dry Char/Refuse	61.18		
34	Carbon Monoxide (PPM)	118.94	TOTAL CARBON CONVERSION	97.50		
35	Sulfur Dioxide (PPM)	540.05	COAL CARBON CONVERSION	97.50		
36	Oxides of Nitrogen (PPM)	474.31				
37						
38						
39						
40						
41						
42						

	A	B	C	D	E	F
43			Summary of Boiler Performance			
44						
45						
46	Date of Operation	5-Sep				
47						
48						
49						
50						
51	Boiler Operating Conditions					
52						
53						
54	Total Firing Rate		15.95729518	MMBtu/h		
55	Gas Support (%)		0.00	%		
56	Excess air used (%)		19.60	%		
57						
58	Actual mass of products of combustion =		15949.55197	lb/lb of "as fired" fuel		
59						
60	Theoretical flue gas composition	%				
61	Carbon Dioxide	14.50				
62	Water vapor	5.82				
63	Oxygen	3.32				
64	Nitrogen	76.30				
65	Sulfur Dioxide (ppm)	557				
66	Total	100.00				
67	Boiler Efficiency Details					
68				%		
69	1. Heat loss due to Dry gas (%)			6.51		
70	2. Heat loss due to unburned carbon			2.03		
71	3. Heat loss due to unburned carbon in dust			Negligible		
72	4. Heat loss due to moisture in "as Fired Fuel"			0.06		
73	5. Heat loss due to moisture produced from burning hydrogen in fuel			3.78		
74	6. Heat loss due to moisture in combustion air			0.16		
75	7. Heat loss due to formation of carbon monoxide			0.04		
76	8. Heat loss due to radiation			1.30		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			13.89		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-84.19	Btu/lb of "as fired fuel"	
81	2. Heat supplied by mill to primary (transport) air			45.87	Btu/lb of "as fired fuel"	
82						
83	BOILER EFFICIENCY (%)			86.07		
84						
85						

Boiler Performance Calculations

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4		Conversion of Gas Composition from Volume % to Wt%									
5	Fuel Gas Composition (Dry. Vol%)			Density at 60°F (lb/cu.ft)	lbs in each Cu.ft of gas						
6	Methane	95.54		0.04246	0.04056628		N. Gas Composition (Wt%, d.b)			As Fired (wt%)	
7	Ethane	2.48		0.08029	0.00199119		Carbon	73.40		73.3583626	
8	Propane	0		0.1196	0		Hydrogen	24.01		23.9954486	
9	Butane	0.43		0.1582	0.00068026		Nitrogen	2.60		2.59618878	
10	Hydrogen Sulfide	0		0.09109	0		Sulfur	0.00		0	
11	Carbon Dioxide	0		0.117	0		Oxygen	0.00		0	
12	Nitrogen	1.55		0.07439	0.00115305		Moisture	0.00		0.05	
13	Total	100					Total=	100.00		100.00	
14			Density of N. gas (lb/cu.ft) =		0.04439078						
15											
16											
17											
18		Determination of Percent Gas Support									
19											
20											
21											
22	Coal Firing Rate (lb/h)	1098									
23	Coal Heat Input(Btu/h)	15957234		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
24				Carbon	81.43		Carbon	81.43			
25	Gas Heat Input (Btu/h)	0		Hydrogen	5.17		Hydrogen	5.17			
26	Total Firing Rate	15957234		Nitrogen	1.40		Nitrogen	1.40			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.83		Sulfur	0.83			
28	Gas Firing Rate (lb/h)	0		Oxygen	6.10		Oxygen	6.10			
29	Gas Support (% of Heat)	0.00		Ash	4.31		Ash	4.31			
30	Fraction of coal	1		Moisture	0.75		Moisture	0.75			
31	Fraction of GAS	0		Total	100.00		Total	100.00			
32											
33				HHV	14533		HHV	14533			
34				Dry ash%	4.34		Dry Ash	4.34			
35											
36											
37											
38											
39											
40											
41											
42											

	G	H	I	J	K	L	M	N	O	P	Q
43	Calculation of Air Requirement and Theoretical Products of Composition										
44											
45											
46	Carbon= %C/(100*12) *1mole =		Theoretical Oxygen Requirement 0.06786219	moles							
47	Hydrogen= %H/(100*2)*0.5 mole =		0.01292731	moles							
48	Sulfur= %S/(100*32) *1 mole =		0.00026053	moles							
49											
50	Oxygen required= Sum of the 3		0.08105003	moles							
51	Oxygen available in the Fuel= %O/(100*32)		0.00190746								
52	Net Oxygen required =		0.07914257	moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =										
54			0.37686938	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= 100(O2-CO/2)/(0.264*N2-(O2-CO/2)=			19.60					
59											
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.45073215					
61	Dry air in lbs/lb of "as fired" fuel			= moles of air*29.97 =		13.5084426					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80"F)=										
64		=	lbs of dry air * 1.0013			13.5260036					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67					14.5260036	lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69											
70			=		15949.552	lb of flue gas					
71											
72											
73											
74											
75											
76											
77											
78											
79											
80											
81											
82											
83											
84											
85											

	R	S	T	U	V	W	X	Y	Z	AA
1	**Calculation of Theoretical Composition of Products**									
2										
3										
4					Wet Flue Gas Compositon (%)			Dry Flue Gas Comp. (%)		
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06786219	14.50			15.40		
6	Water	(moles of water in fuel +moles								
7		of water in combustion air)		0.0272469	5.82			0.00		
8	Oxygen			0.01551118	3.32			3.52		
9	Nitrogen			0.35700561	76.30			81.02		
10	Sulfur Dioxide			0.00026053	0.05568259			0.06		
11	Total			0.46788641	100.00			100.00		
12										
13										
14	**Boiler**	**Efficiency**	**Calculations**							
15										
16	These calculations are based on ASME PTC 4.1using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg' =	((c% d.b) * C.Efficiency *(44.01 (CO2) + 32.00 (O2) + 28.02 (N2) + (28.01 (CO)/12.01 (CO2+CO)) + 12.01 (S)/32.07								
21										
22		12.76327165	lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		Lwg' = Wg' * 0.24 * (359-75)/HHV *100			=	6.51			
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500				=	2.03			
30										
31										
32	3. Heat loss due to unburned carbon in dust						Negligible			
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"					=	0.06			
36										
37	Lmf=	Moisture in Fuel (Entahlpy of vapor at gas leaving temp -								
38			Enthalpy of water at mill inlet)/HHV*100							
39										
40										
41	5. Heat loss due to moisture produced from burning hydrogen in fuel					=	3.78			
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmfh=	8.936 *% hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater-								
44			Enthalpy of water at mill inlet temp)/HHV							
45										
46	6. Heat loss due to moisture in combustion air					=	0.16			
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel									
48		=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV=							
49										
50		=	10.94	lb/lb of "as fired" fuel						
51										
52	Actual dry air =	(1+% Excess air/100) lb/lb of "as fired" fuel								
53		13.09	lb							
54	Moisture in air =	0.013 lb /lb of dry air		0.170111	lbs/lb of "as fired" fuel					
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -								
56			enthalpy of vapor at mill inlet temp.)							
57										
58										
59	7. Heat loss due to formation of carbon monoxide					=	0.04			
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in 'as fired fuel								
61										
62										
63	8. Heat loss due to radiation		10 exp (0.62-0.42log Q)				1.30			
64										
65										
66										
67										
68	Total Losses (%)						13.89	%		
69	HEAT CREDITS									
70										
71	1. Heat supplied by duct burner to entering air					-84.19	Btu/lb of "as Fired" Fuel			
72	2. Heat supplied by mill to primary (transport) air					45.87	Btu/lb of "as Fired" Fuel			
73										
74	Boiler Efficiency (%)=						86.07	%		
75										
76										
77	Combustion Air Flow (lb,hr)=									
78							14555	lb/h		
79										
80										
81										
82										
83										
84										
85										