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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

Ramesh Patel, Richard W. Borio, Greg Liljedahl
ABB Power Plant Laboratories
Combustion Engineering, Inc., Windsor CT 06095

Bruce G. Miller, Alan W. Scaroni
Energy and Fuels Research Center
The Pennsylvania State University, University Park PA 16802

Jon G. McGowan
University of Massachusetts, Amherst MA 01002

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 NO_x 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 NO_x 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 ft³, 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

	<u>Brookville Seam</u>	<u>Kentucky</u>
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

	<ul style="list-style-type: none"> • Typical mill air flow rate: 370-400 acfm • Typical coal feed rate: 16.5- 18.5 lb/min 	
<u>Particle Size (microns)</u>	<u>Brookville Seam Coal</u>	<u>Kentucky Coal</u>
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
NO _x at 3% O ₂ (ppm)	413 (0.56 lb/MBtu)
Burner Pressure Drop (in H ₂ O)	8

During this test program, key performance variables were monitored in detail: boiler efficiency, combustion efficiency, and NO_x 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).

NO_x Emissions

The NO_x emissions target was 0.6 lb NO_x per million Btu fired; this translates to about 450 ppm at 3% O₂. Testing with 100% microfine coal showed that this target was achieved (in general a NO_x emissions value of 0.56 lb NO_x per million Btu was routinely met) while meeting nearly all other required conditions. It is acknowledged that the optimum conditions for low NO_x 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 NO_x 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 NO_x 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 NO_x 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 target 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 (approximately 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%
- NO_x 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 NO_x 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

[illegible]

Table 1. Burner Characterization Summary

Date	Time	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q38	Q39	Q40	Q41	Q42	Q43	Q44	Q45	Q46	Q47	Q48	Q49	Q50	Q51	Q52	Q53	Q54	Q55	Q56	Q57	Q58	Q59	Q60	Q61	Q62	Q63	Q64	Q65	Q66	Q67	Q68	Q69	Q70	Q71	Q72	Q73	Q74	Q75	Q76	Q77	Q78	Q79	Q80	Q81	Q82	Q83	Q84	Q85	Q86	Q87	Q88	Q89	Q90	Q91	Q92	Q93	Q94	Q95	Q96	Q97	Q98	Q99	Q100	Q101	Q102	Q103	Q104	Q105	Q106	Q107	Q108	Q109	Q110	Q111	Q112	Q113	Q114	Q115	Q116	Q117	Q118	Q119	Q120	Q121	Q122	Q123	Q124	Q125	Q126	Q127	Q128	Q129	Q130	Q131	Q132	Q133	Q134	Q135	Q136	Q137	Q138	Q139	Q140	Q141	Q142	Q143	Q144	Q145	Q146	Q147	Q148	Q149	Q150	Q151	Q152	Q153	Q154	Q155	Q156	Q157	Q158	Q159	Q160	Q161	Q162	Q163	Q164	Q165	Q166	Q167	Q168	Q169	Q170	Q171	Q172	Q173	Q174	Q175	Q176	Q177	Q178	Q179	Q180	Q181	Q182	Q183	Q184	Q185	Q186	Q187	Q188	Q189	Q190	Q191	Q192	Q193	Q194	Q195	Q196	Q197	Q198	Q199	Q200	Q201	Q202	Q203	Q204	Q205	Q206	Q207	Q208	Q209	Q210	Q211	Q212	Q213	Q214	Q215	Q216	Q217	Q218	Q219	Q220	Q221	Q222	Q223	Q224	Q225	Q226	Q227	Q228	Q229	Q230	Q231	Q232	Q233	Q234	Q235	Q236	Q237	Q238	Q239	Q240	Q241	Q242	Q243	Q244	Q245	Q246	Q247	Q248	Q249	Q250	Q251	Q252	Q253	Q254	Q255	Q256	Q257	Q258	Q259	Q260	Q261	Q262	Q263	Q264	Q265	Q266	Q267	Q268	Q269	Q270	Q271	Q272	Q273	Q274	Q275	Q276	Q277	Q278	Q279	Q280	Q281	Q282	Q283	Q284	Q285	Q286	Q287	Q288	Q289	Q290	Q291	Q292	Q293	Q294	Q295	Q296	Q297	Q298	Q299	Q300	Q301	Q302	Q303	Q304	Q305	Q306	Q307	Q308	Q309	Q310	Q311	Q312	Q313	Q314	Q315	Q316	Q317	Q318	Q319	Q320	Q321	Q322	Q323	Q324	Q325	Q326	Q327	Q328	Q329	Q330	Q331	Q332	Q333	Q334	Q335	Q336	Q337	Q338	Q339	Q340	Q341	Q342	Q343	Q344	Q345	Q346	Q347	Q348	Q349	Q350	Q351	Q352	Q353	Q354	Q355	Q356	Q357	Q358	Q359	Q360	Q361	Q362	Q363	Q364	Q365	Q366	Q367	Q368	Q369	Q370	Q371	Q372	Q373	Q374	Q375	Q376	Q377	Q378	Q379	Q380	Q381	Q382	Q383	Q384	Q385	Q386	Q387	Q388	Q389	Q390	Q391	Q392	Q393	Q394	Q395	Q396	Q397	Q398	Q399	Q400	Q401	Q402	Q403	Q404	Q405	Q406	Q407	Q408	Q409	Q410	Q411	Q412	Q413	Q414	Q415	Q416	Q417	Q418	Q419	Q420	Q421	Q422	Q423	Q424	Q425	Q426	Q427	Q428	Q429	Q430	Q431	Q432	Q433	Q434	Q435	Q436	Q437	Q438	Q439	Q440	Q441	Q442	Q443	Q444	Q445	Q446	Q447	Q448	Q449	Q450	Q451	Q452	Q453	Q454	Q455	Q456	Q457	Q458	Q459	Q460	Q461	Q462	Q463	Q464	Q465	Q466	Q467	Q468	Q469	Q470	Q471	Q472	Q473	Q474	Q475	Q476	Q477	Q478	Q479	Q480	Q481	Q482	Q483	Q484	Q485	Q486	Q487	Q488	Q489	Q490	Q491	Q492	Q493	Q494	Q495	Q496	Q497	Q498	Q499	Q500	Q501	Q502	Q503	Q504	Q505	Q506	Q507	Q508	Q509	Q510	Q511	Q512	Q513	Q514	Q515	Q516	Q517	Q518	Q519	Q520	Q521	Q522	Q523	Q524	Q525	Q526	Q527	Q528	Q529	Q530	Q531	Q532	Q533	Q534	Q535	Q536	Q537	Q538	Q539	Q540	Q541	Q542	Q543	Q544	Q545	Q546	Q547	Q548	Q549	Q550	Q551	Q552	Q553	Q554	Q555	Q556	Q557	Q558	Q559	Q560	Q561	Q562	Q563	Q564	Q565	Q566	Q567	Q568	Q569	Q570	Q571	Q572	Q573	Q574	Q575	Q576	Q577	Q578	Q579	Q580	Q581	Q582	Q583	Q584	Q585	Q586	Q587	Q588	Q589	Q590	Q591	Q592	Q593	Q594	Q595	Q596	Q597	Q598	Q599	Q600	Q601	Q602	Q603	Q604	Q605	Q606	Q607	Q608	Q609	Q610	Q611	Q612	Q613	Q614	Q615	Q616	Q617	Q618	Q619	Q620	Q621	Q622	Q623	Q624	Q625	Q626	Q627	Q628	Q629	Q630	Q631	Q632	Q633	Q634	Q635	Q636	Q637	Q638	Q639	Q640	Q641	Q642	Q643	Q644	Q645	Q646	Q647	Q648	Q649	Q650	Q651	Q652	Q653	Q654	Q655	Q656	Q657	Q658	Q659	Q660	Q661	Q662	Q663	Q664	Q665	Q666	Q667	Q668	Q669	Q670	Q671	Q672	Q673	Q674	Q675	Q676	Q677	Q678	Q679	Q680	Q681	Q682	Q683	Q684	Q685	Q686	Q687	Q688	Q689	Q690	Q691	Q692	Q693	Q694	Q695	Q696	Q697	Q698	Q699	Q700	Q701	Q702	Q703	Q704	Q705	Q706	Q707	Q708	Q709	Q710	Q711	Q712	Q713	Q714	Q715	Q716	Q717	Q718	Q719	Q720	Q721	Q722	Q723	Q724	Q725	Q726	Q727	Q728	Q729	Q730	Q731	Q732	Q733	Q734	Q735	Q736	Q737	Q738	Q739	Q740	Q741	Q742	Q743	Q744	Q745	Q746	Q747	Q748	Q749	Q750	Q751	Q752	Q753	Q754	Q755	Q756	Q757	Q758	Q759	Q760	Q761	Q762	Q763	Q764	Q765	Q766	Q767	Q768	Q769	Q770	Q771	Q772	Q773	Q774	Q775	Q776	Q777	Q778	Q779	Q780	Q781	Q782	Q783	Q784	Q785	Q786	Q787	Q788	Q789	Q790	Q791	Q792	Q793	Q794	Q795	Q796	Q797	Q798	Q799	Q800	Q801	Q802	Q803	Q804	Q805	Q806	Q807	Q808	Q809	Q810	Q811	Q812	Q813	Q814	Q815	Q816	Q817	Q818	Q819	Q820	Q821	Q822	Q823	Q824	Q825	Q826	Q827	Q828	Q829	Q830	Q831	Q832	Q833	Q834	Q835	Q836	Q837	Q838	Q839	Q840	Q841	Q842	Q843	Q844	Q845	Q846	Q847	Q848	Q849	Q850	Q851	Q852	Q853	Q854	Q855	Q856	Q857	Q858	Q859	Q860	Q861	Q862	Q863	Q864	Q865	Q866	Q867	Q868	Q869	Q870	Q871	Q872	Q873	Q874	Q875	Q876	Q877	Q878	Q879	Q880	Q881	Q882	Q883	Q884	Q885	Q886	Q887	Q888	Q889	Q890	Q891	Q892	Q893	Q894	Q895	Q896	Q897	Q898	Q899	Q900	Q901	Q902	Q903	Q904	Q905	Q906	Q907	Q908	Q909	Q910	Q911	Q912	Q913	Q914	Q915	Q916	Q917	Q918	Q919	Q920	Q921	Q922	Q923	Q924	Q925	Q926	Q927	Q928	Q929	Q930	Q931	Q932	Q933	Q934	Q935	Q936	Q937	Q938	Q939	Q940	Q941	Q942	Q943	Q944	Q945	Q946	Q947	Q948	Q949	Q950	Q951	Q952	Q953	Q954	Q955	Q956	Q957	Q958	Q959	Q960	Q961	Q962	Q963	Q964	Q965	Q966	Q967	Q968	Q969	Q970	Q971	Q972	Q973	Q974	Q975	Q976	Q977	Q978	Q979	Q980	Q981	Q982	Q983	Q984	Q985	Q986	Q987	Q988	Q989	Q990	Q991	Q992	Q993	Q994	Q995	Q996	Q997	Q998	Q999	Q1000
12/10/15	12:30	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									

Table 1. Burner Characterization Summary

Dist.	Line	Q ₁ (in)	Q ₂ (in)	Q ₃ (in)	Q ₄ (in)	Q ₅ (in)	Q ₆ (in)	Q ₇ (in)	Q ₈ (in)	Q ₉ (in)	Q ₁₀ (in)	Q ₁₁ (in)	Q ₁₂ (in)	Q ₁₃ (in)	Q ₁₄ (in)	Q ₁₅ (in)	Q ₁₆ (in)	Q ₁₇ (in)	Q ₁₈ (in)	Q ₁₉ (in)	Q ₂₀ (in)	Q ₂₁ (in)	Q ₂₂ (in)	Q ₂₃ (in)	Q ₂₄ (in)	Q ₂₅ (in)	Q ₂₆ (in)	Q ₂₇ (in)	Q ₂₈ (in)	Q ₂₉ (in)	Q ₃₀ (in)	Q ₃₁ (in)	Q ₃₂ (in)	Q ₃₃ (in)	Q ₃₄ (in)	Q ₃₅ (in)	Q ₃₆ (in)	Q ₃₇ (in)	Q ₃₈ (in)	Q ₃₉ (in)	Q ₄₀ (in)	Q ₄₁ (in)	Q ₄₂ (in)	Q ₄₃ (in)	Q ₄₄ (in)	Q ₄₅ (in)	Q ₄₆ (in)	Q ₄₇ (in)	Q ₄₈ (in)	Q ₄₉ (in)	Q ₅₀ (in)	Q ₅₁ (in)	Q ₅₂ (in)	Q ₅₃ (in)	Q ₅₄ (in)	Q ₅₅ (in)	Q ₅₆ (in)	Q ₅₇ (in)	Q ₅₈ (in)	Q ₅₉ (in)	Q ₆₀ (in)	Q ₆₁ (in)	Q ₆₂ (in)	Q ₆₃ (in)	Q ₆₄ (in)	Q ₆₅ (in)	Q ₆₆ (in)	Q ₆₇ (in)	Q ₆₈ (in)	Q ₆₉ (in)	Q ₇₀ (in)	Q ₇₁ (in)	Q ₇₂ (in)	Q ₇₃ (in)	Q ₇₄ (in)	Q ₇₅ (in)	Q ₇₆ (in)	Q ₇₇ (in)	Q ₇₈ (in)	Q ₇₉ (in)	Q ₈₀ (in)	Q ₈₁ (in)	Q ₈₂ (in)	Q ₈₃ (in)	Q ₈₄ (in)	Q ₈₅ (in)	Q ₈₆ (in)	Q ₈₇ (in)	Q ₈₈ (in)	Q ₈₉ (in)	Q ₉₀ (in)	Q ₉₁ (in)	Q ₉₂ (in)	Q ₉₃ (in)	Q ₉₄ (in)	Q ₉₅ (in)	Q ₉₆ (in)	Q ₉₇ (in)	Q ₉₈ (in)	Q ₉₉ (in)	Q ₁₀₀ (in)	Q ₁₀₁ (in)	Q ₁₀₂ (in)	Q ₁₀₃ (in)	Q ₁₀₄ (in)	Q ₁₀₅ (in)	Q ₁₀₆ (in)	Q ₁₀₇ (in)	Q ₁₀₈ (in)	Q ₁₀₉ (in)	Q ₁₁₀ (in)	Q ₁₁₁ (in)	Q ₁₁₂ (in)	Q ₁₁₃ (in)	Q ₁₁₄ (in)	Q ₁₁₅ (in)	Q ₁₁₆ (in)	Q ₁₁₇ (in)	Q ₁₁₈ (in)	Q ₁₁₉ (in)	Q ₁₂₀ (in)	Q ₁₂₁ (in)	Q ₁₂₂ (in)	Q ₁₂₃ (in)	Q ₁₂₄ (in)	Q ₁₂₅ (in)	Q ₁₂₆ (in)	Q ₁₂₇ (in)	Q ₁₂₈ (in)	Q ₁₂₉ (in)	Q ₁₃₀ (in)	Q ₁₃₁ (in)	Q ₁₃₂ (in)	Q ₁₃₃ (in)	Q ₁₃₄ (in)	Q ₁₃₅ (in)	Q ₁₃₆ (in)	Q ₁₃₇ (in)	Q ₁₃₈ (in)	Q ₁₃₉ (in)	Q ₁₄₀ (in)	Q ₁₄₁ (in)	Q ₁₄₂ (in)	Q ₁₄₃ (in)	Q ₁₄₄ (in)	Q ₁₄₅ (in)	Q ₁₄₆ (in)	Q ₁₄₇ (in)	Q ₁₄₈ (in)	Q ₁₄₉ (in)	Q ₁₅₀ (in)	Q ₁₅₁ (in)	Q ₁₅₂ (in)	Q ₁₅₃ (in)	Q ₁₅₄ (in)	Q ₁₅₅ (in)	Q ₁₅₆ (in)	Q ₁₅₇ (in)	Q ₁₅₈ (in)	Q ₁₅₉ (in)	Q ₁₆₀ (in)	Q ₁₆₁ (in)	Q ₁₆₂ (in)	Q ₁₆₃ (in)	Q ₁₆₄ (in)	Q ₁₆₅ (in)	Q ₁₆₆ (in)	Q ₁₆₇ (in)	Q ₁₆₈ (in)	Q ₁₆₉ (in)	Q ₁₇₀ (in)	Q ₁₇₁ (in)	Q ₁₇₂ (in)	Q ₁₇₃ (in)	Q ₁₇₄ (in)	Q ₁₇₅ (in)	Q ₁₇₆ (in)	Q ₁₇₇ (in)	Q ₁₇₈ (in)	Q ₁₇₉ (in)	Q ₁₈₀ (in)	Q ₁₈₁ (in)	Q ₁₈₂ (in)	Q ₁₈₃ (in)	Q ₁₈₄ (in)	Q ₁₈₅ (in)	Q ₁₈₆ (in)	Q ₁₈₇ (in)	Q ₁₈₈ (in)	Q ₁₈₉ (in)	Q ₁₉₀ (in)	Q ₁₉₁ (in)	Q ₁₉₂ (in)	Q ₁₉₃ (in)	Q ₁₉₄ (in)	Q ₁₉₅ (in)	Q ₁₉₆ (in)	Q ₁₉₇ (in)	Q ₁₉₈ (in)	Q ₁₉₉ (in)	Q ₂₀₀ (in)	Q ₂₀₁ (in)	Q ₂₀₂ (in)	Q ₂₀₃ (in)	Q ₂₀₄ (in)	Q ₂₀₅ (in)	Q ₂₀₆ (in)	Q ₂₀₇ (in)	Q ₂₀₈ (in)	Q ₂₀₉ (in)	Q ₂₁₀ (in)	Q ₂₁₁ (in)	Q ₂₁₂ (in)	Q ₂₁₃ (in)	Q ₂₁₄ (in)	Q ₂₁₅ (in)	Q ₂₁₆ (in)	Q ₂₁₇ (in)	Q ₂₁₈ (in)	Q ₂₁₉ (in)	Q ₂₂₀ (in)
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Table 2. Summary of Natural Gas Baseline Testing

ABB COMBUSTION ENGINEERING BASELINE GAS SUMMARY					
TEST/DESCRIPTION:	7/25/95	7/25/95	7/25/95	7/26/95	8/1/95
	3% O ₂	2% O ₂	1% O ₂	1% O ₂	1.5% O ₂
	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 H ₂ O	-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					
O ₂ ; %	3.1	2.1	1.1	1.5	1.8
CO; ppm	45	49	108	37	73
CO ₂ ; %	9.6	10.2	10.6	11.0	11.2
SO ₂ ; ppm	NA	NA	NA	NA	NA
NO _x ; ppm	44	44	43	26	48
Particulates; gr/SCF	NA	NA	NA	NA	NA
O ₂ before and after air heater; %, %	3.1, Not	2.1, NM	1.1, NM	1.5, NM	1.8, NM
	Measured(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 consumption; 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	Tert. 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	14,849	14,442
Boiler draft; in H ₂ O	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					
O ₂ ; %	3.5	2.7	3.4	3.8	3.3
CO; ppm;lb/MMBtu@3%O ₂	238;0.20	149;0.12	258;0.22	146;0.13	178;0.15
CO ₂ ; %	15.8	16.5	15.6	15.0	15.3
SO ₂ ; ppm;lb/MMBtu@3%O ₂	512;1.00	552;0.99	583;1.11	485;0.97	529;1.00
NO _x ; ppm;lb/MMBtu@3%O ₂	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	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 consumption; 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); %	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 H ₂ O	-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					
O ₂ ; %	3.5	3.6	3.8	3.5	3.5
CO; ppm;lb/MMBtu@3%O ₂	129;0.11	166;0.14	114;0.10	118;0.10	119;0.10
CO ₂ ; %	15.4	15.4	15.3	15.6	15.9
SO ₂ ; ppm;lb/MMBtu@3%O ₂	474;0.92	511;1.00	538;1.08	478;0.95	540;1.07
NO _x ; ppm;lb/MMBtu@3%O ₂	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 consumption; 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)		Top Size	Particle Size, in Microns, that is Less Than the Indicated Size					
						Air Inlet	Mill Outlet		<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	60.5	35.7	20.3	5.1
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	54.6	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	383	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
<u>Operating Conditions</u>				
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
<u>Particle Size (μm)</u>				
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. O₂ AND CO CONCENTRATION vs. TIME FOR TESTING CONDUCTED ON 12/07/93

Figure 3. O₂ AND CO CONCENTRATION vs. TIME FOR TESTING CONDUCTED ON 04/28/94
T_O = 5:39AM

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

Figure 5. O₂ AND CO CONCENTRATION vs. TIME FOR TESTING CONDUCTED ON 08/23/95

Figure 6. O₂ AND CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/25/95
T_O at 14:30

Figure 7. O₂ AND CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/28/95

Figure 8. O₂ and CO CONCENTRATION vs TIME FOR TESTING CONDUCTED ON 08/30/95

Figure 9. O₂ 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

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 O₂ CONCENTRATION FOR THE HEACC AND HEACC-2

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

(a)

(b)

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

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

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

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

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

(a)

(b)

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**

**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% O₂

07/25/95 -- 75% load, 2% O₂

07/25/95 -- 75% load, 3% O₂

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	Enthalpy 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	Enthalpy of water at fuel inlet temp. (Btu/lb)	42	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	384	Enthalpy 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			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											
46	Carbon= $\%C/(100 \cdot 12) \cdot 1 \text{ mole} =$			Theoretical Oxygen Requirement							
47	Hydrogen= $\%H/(100 \cdot 2) \cdot 0.5 \text{ mole} =$			0.06113197 moles							
48	Sulfur= $\%S/(100 \cdot 32) \cdot 1 \text{ mole} =$			0.05998862 moles							
49				0 moles							
50	Oxygen required= Sum of the 3										
51	Oxygen available in the Fuel= $\%O/(100 \cdot 32)$			0.12112059 moles							
52	Net Oxygen required =			0							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =			0.12112059 moles							
54				0.57676472 moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)										
59						4.93					
60	Actual Dry air Required (moles) = $(1+E.A.) \cdot \text{total air required} =$										
61	Dry air in lbs/lb of "as fired" fuel					0.60518525					
62						18.137402					
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=										
64						18.1609806					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67											
68	Actual weight of products =					19.1609806 lb/lb of fuel					
69						10.864 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 Composition (%)			Dry Flue Gas Comp. (%)	
6	Water	(moles of water in fuel +moles of water in combustion air)			9.16			11.19	
7									
8	Oxygen			0.12131494	18.18			0.00	
9	Nitrogen			0.00596831	0.89			1.09	
10	Sulfur Dioxide			0.47902356	71.77			87.71	
11	Total			0	0			0.00	
12	Carbon Conversion	100	Carbon Conversion of Coal	0.66743879	100.00			100.00	
13		100.00							
14	Boiler	Efficiency	Calculations						
15									
16	These calculations are based on ASME PTC 4.1 using 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 (CO ₂) + 32.00 (O ₂) + 28.02 (N ₂) + (28.01 (CO)/12.01 (CO ₂ +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 (Enthalpy 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	=		10.40		
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								
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			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.)				0.11		
57									
58									
59	7. Heat loss due to formation of carbon monoxide								
60	Lco =	CO/(CO ₂ +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 (%)=						83.14	%	
75									
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	Enthalpy 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 Givg 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		

	G	H	I	J	K	L	M	N	O	P	Q
1											
2											
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6											
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9											
10											
11											
12											
13											
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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(O ₂ -CO ₂)/(0.264*N ₂ -(O ₂ -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=					20.0324711	lb/lb of fuel				
67											
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69											
70						11,358	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									
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06113197	8.78			10.63	
6	Water	(moles of water in fuel +moles of water in combustion air)		0.1213778	17.43			0.00	
7				0.01206692	1.73			2.10	
8	Oxygen			0.50196596	72.07			87.27	
9	Nitrogen			0	0			0.00	
10	Sulfur Dioxide			0.69654265	100.00			100.00	
11	Total								
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 4.1 using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	$W_g =$	$((c\% \text{ d.b}) \cdot C.Efficiency \cdot \{44.01 (CO_2) + 32.00 (O_2) + 28.02 (N_2) + (28.01 (CO)/12.01 (CO_2+CO)) + 12.01 (S)/32.07$							
21									
22		17.7975154	lb/lb of as fired fuel						
23									
24	1. Heat loss due to dry gas (%)	$L_{wg} = W_g \cdot 0.24 \cdot (\text{Gas lvg temp from air heater - mill inlet temp})/HHV \cdot 100$				=	5.05		
25									
26									
27	2. Heat loss due to unburned carbon								
28									
29	$L_{uc} =$	$\% \text{ Carbon in the "as fired Fuel"} \cdot (1 - \text{Comb.Efficiency}) \cdot 14,500$				=	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	$L_{mf} =$	Moisture in Fuel (Enthalpy 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	Lm/h =	8.936 % hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater -							
44		Enthalpy of water at mill inlet temp)/HHV					10.40		
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								
48	=	(11.52(% carbon) + 34.57(% hydrogen-% oxygen/8) + 4.32 (% sulfur))/HHV =							
49									
50									
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							
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater -							
56		enthalpy of vapor at mill inlet temp.)					0.12		
57									
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								
64		10 exp (0.62-0.42log Q)					1.41		
65									
66									
67									
68	Total Losses (%)						16.99 %		
69	HEAT CREDITS								
70									
71	1. Heat supplied by duct burner to entering air								
72	2. Heat supplied by primary (transport) air								
73									
74	Boiler Efficiency (%) =								
75									
76	Combustion Air Flow (%) =								
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						
4	Pressures and Temperatures		100% Gas; Prim. Open, Sec. Open, Tert. 25% Open, Gas Gun -4", Coal Gun Out, 3% O2			
5			Steam Data			
6	Drum Steam Pressure (Psig)	199	Enthalpy of Sat. Liq. (Btu/lb)	355		
7	Feed Water Temperature (°F)	206	Enthalpy of Feed Water (Btu/lb)	175	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (%)	99.5	Steam Production Rate (PPH)	12,404		
9	Gas Temp. Leaving Boiler (°F)	525	Blow down Rate (PPH)	3,093		
10	Gas Temp. Leaving Air Heater (°F)	354	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1176	(Sup. steam @ 1psia & gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	175	Enthalpy of water at fuel inlet temp. (Btu/lb)	53	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	383	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1060	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	363				
14	Mill Inlet Temperature (°F)	85				
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%)		Carbon	0	Methane	95.54
22	Ash (Wt%)		Hydrogen	0	Ethane	2.48
23			Nitrogen	0	Propane	0
24	HHV (Btu/lb., d.b)		Sulfur	0	Butane	0.43
25			Oxygen	0	Hydrogen Sulfide	0
26			Ash	0	Carbon Dioxide	1.55
27			Total	0	Nitrogen	
28					Others	
29					Total	100
30	Flue Gas Analysis				Moisture (wt%)	0.05
31						
32	Oxygen (%)	3.1				
33	Carbon Dioxide (%)	9.6	Ash in Dry Char/Refuse	0		
34	Carbon Monoxide (PPM)	45	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 (%)		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 produced from burning hydrogen in fuel			0.12		
75	7. Heat loss due to moisture in combustion air			0.01		
76	8. Heat loss due to formation of carbon monoxide			1.41		
77	9. Heat loss due to radiation			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(O ₂ -C _O /2)/(0.264*N ₂ -(O ₂ -C _O /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 Composition (%)			Dry Flue Gas Comp. (%)	
6	Water	(moles of water in fuel +moles of water in combustion air)			8.39			10.07	
7				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 4.1 using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	Wg' =	$((\text{C\% d.b}) \cdot \text{C.Efficiency} \cdot (44.01 (\text{CO}_2) + 32.00 (\text{O}_2) + 28.02 (\text{N}_2) + (28.01 (\text{CO})/12.01 (\text{CO}_2 + \text{CO})) + 12.01 (\text{S})/32.07$							
21									
22		18.87437722	lb/lb of as fired fuel						
23									
24	1. Heat loss due to dry gas (%)	$\text{Lwg}' = \text{Wg}' \cdot 0.24 \cdot (\text{Gas lvg temp from air heater - mill inlet temp})/\text{HHV} \cdot 100$						5.22	
25									
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =	% Carbon in the "as fired Fuel" $\cdot (1 - \text{Comb.Efficiency}) \cdot 14,500$						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 (Enthalpy 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	Lm/h=	8.936	% hydrogen in "as fired" fuel	(Enthalpy of vapor leaving air heater -					
44			Enthalpy of water at mill inlet temp)/HHV	=			10.31		
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								
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		19.35	lb						
54	Moisture in air =	0.013	lb /lb of dry air						
55	Lma =	0.2515058	lbs/lb of "as fired" fuel						
56			moisture in air * (enthalpy of water vapor leaving air heater -						
57			enthalpy of vapor at mill inlet temp.)				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	=		0.01		
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 (%)								
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	Enthalpy 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	Enthalpy of water at fuel inlet temp. (Btu/lb)	59	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	409	Enthalpy 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		17.089272 MMBtu/h			
55	Gas Support (%)		100.00%			
56	Excess air used (%)		6.94%			
57						
58	Actual mass of products of combustion =		14280.2447 lb/lb of "as fired" fuel			
59						
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 (%)			5.09		
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			10.41		
74	6. Heat loss due to moisture in combustion air			0.13		
75	7. Heat loss due to formation of carbon monoxide			0.01		
76	8. Heat loss due to radiation			1.27		
77	9. Heat loss due to steam drum blowdown			0.00		
78	Total Losses			16.91		
79	Heat Credits					
80	1. Heat supplied by duct burner to entering air			-80.16 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 (%)			83.03		

	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			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		As Fired Coal Composition (Wt)			"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
23	Coal Heat Input(Btu/h)	0		Carbon	0.00		Carbon	73.36			
24				Hydrogen	0.00		Hydrogen	24.00			
25	Gas Heat Input (Btu/h)	17089272		Nitrogen	0.00		Nitrogen	2.60			
26	Total Firing Rate	17089272		Sulfur	0.00		Sulfur	0.00			
27	Gas Calorific Value (Btu/lb)	23346		Oxygen	0.00		Oxygen	0.00			
28	Gas Firing Rate (lb/h)	732		Ash	0.00		Ash	0.00			
29	Gas Support (% of Heat)	100.00		Moisture	0		Moisture	0.05			
30	Fraction of coal	0		Total	0		Total	100.00			
31	Fraction of GAS	1									
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(O ₂ -C _O /2)/(0.26-1*N ₂ -(O ₂ -C _O /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											
65				lbs of dry air * 1.0013		18.508531					
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								
5	Carbon Dioxide	(=moles of carbon /lb of fuel)	0.06113197	9.00				
6	Water	(moles of water in fuel +moles of water in combustion air)						Dry Flue Gas Comp. (%)
7								10.96
8	Oxygen		0.12134001	17.87				0.00
9	Nitrogen		0.00840044	1.24				1.51
10	Sulfur Dioxide		0.48817299	71.89				87.53
11	Total		0	0				0.00
12	Carbon Conversion	100	0.67904541	100.00				100.00
13		Carbon Conversion of Coal NA						
14	Boiler	Efficiency						
15		Calculations						
16	These calculations are based on ASME PTC 4.1 using heat loss method							
17								
18	1. Pounds of dry gas per pound of "as fired" composite fuel							
19								
20	Wg =	$((c\% \text{ d.b}) \cdot C \cdot \text{Efficiency}) \cdot (44.01 \text{ (CO}_2) + 32.00 \text{ (O}_2) + 28.02 \text{ (N}_2) + (28.01 \text{ (CO)} / 12.01 \text{ (CO}_2 + \text{CO})) + 12.01 \text{ (S)} / 32.07$						
21								
22		16.56327899 lb/lb of as fired fuel						
23								
24	1. Heat loss due to dry gas (%)	$L_{wg} = W_g \cdot 0.24 \cdot (\text{Gas lvg temp from air heater} - \text{mill inlet temp}) / \text{HHV} \cdot 100$						
25								
26								
27	2. Heat loss due to unburned carbon							
28								
29	Luc =	% Carbon in the "as fired Fuel" $\cdot (1 - \text{Comb.Efficiency}) \cdot 14,500$						
30								
31								
32	3. Heat loss due to unburned carbon in dust							
33								
34								
35	4. Heat loss due to moisture in "as Fired Fuel"							
36								
37	Lmf=	Moisture in Fuel (Enthalpy of vapor at gas leaving temp - Enthalpy of water at mill inlet) / HHV $\cdot 100$						
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	L _m lb/h=	8,936	% hydrogen in "as fired" fuel	(Enthalpy of vapor leaving air heater - Enthalpy of water at mill inlet temp)/HHV	=				
44							10.41		
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								
48	=								
49									
50	=								
51									
52	Actual dry air =								
53									
54	Moisture in air =								
55	L _{ma} =								
56									
57									
58									
59	7. Heat loss due to formation of carbon monoxide								
60	L _{co} =								
61									
62									
63	8. Heat loss due to radiation								
64									
65									
66									
67									
68	Total Losses (%)								
69	HEAT CREDITS								
70									
71	1. Heat supplied by duct burner to entering air								
72	2. Heat supplied by primary (transport) air								
73									
74	Boiler Efficiency (%) =								
75									
76	Combustion Air Flow (%) =								
77									
78									
79									
80									
81									
82									
83									

		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		N. Gas Composition (Wt%, d.b)		As Fired (wt%)	
Methane	95.54	0.01246	0.0405663	Carbon	73.40	71.3583626	
Ethane	2.48	0.08029	0.0019912	Hydrogen	24.01	23.9954486	
Propane	0	0.1196	0	Nitrogen	2.60	2.59618878	
Butane	0.41	0.1582	0.0006803	Sulfur	0.00	0	
Hydrogen Sulfide	0	0.09109	0	Oxygen	0.00	0	
Carbon Dioxide	0	0.117	0	Moisture	0.00	0.05	
Nitrogen	1.55	0.07439	0.001153	Total=	100.00	100.00	
Total	100						
Density of N. gas (lb/cu.ft) =		0.0444					
Determination of Percent Gas Support							
Coal Firing Rate (lb/h)	0						
Coal Heat Input(Btu/h)	0						
		As Fired Coal Composition (Wt)		"As Fired" Fuel (coal+nat. gas) Composition (Wt%)			
Gas Heat Input (Btu/h)	8582456.5	Carbon	76.42	Carbon	73.36		
Total Firing Rate	8582456.5	Hydrogen	4.92	Hydrogen	24.00		
Gas Calorific Value (Btu/lb)	23346	Nitrogen	1.45	Nitrogen	2.60		
Gas Firing Rate (lb/h)	367.62	Sulfur	0.50	Sulfur	0.00		
Gas Support (% of Heat)	100.00	Oxygen	6.60	Oxygen	0.00		
Fraction of coal	0	Ash	5.82	Ash	0.00		
Fraction of GAS	1	Moisture	3.42	Moisture	0.05		
		Total	99.13	Total	100.00		
		HHV	13330.937	HHV	23,346		
		Dry ash%	6.03	Dry Ash	0.00		

Calculation of Air Requirement and Theoretical Products of Combustion									
	Theoretical Oxygen Requirement	0.06113197 mols	Hydrogen = $\%H/(100 \cdot 2) \cdot 1 \text{ mole} =$	0.05998862 mols	Sulfur = $\%S/(100 \cdot 32) \cdot 1 \text{ mole} =$	(Oxygen required = Sum of the 3			
						(Oxygen available in the fuel = $\%O/(100 \cdot 32) =$			
		0.12112059 mols		0.12112059 mols		Net Oxygen required =			
Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =						0.12112059 mols			
0.57676472 mols/lb of as fired fuel									
Calculation of Products of Combustion									
Excess air used (%)						$= 100(CO_2 + CO)/(O_2 + N_2) (O_2 + CO_2) =$			
						8.49			
Actual Dry Air Required (mols) = $(1 + E.A\%) \cdot \text{total air required} =$						0.62571148			
Dry air in lbs/lb of "as fired" fuel						$= \text{mols of air} \cdot 29.97 =$			
						18.752573			
Actual wet air used/lb of "as fired" fuel (assuming 60% R.H. and 80°F) =									
						$\text{lbs of dry air} \cdot 1.0013$			
Weight of products of combustion = Actual wet air used + weight of fuel =						18.7769514			
Actual weight of products =						19.776951 mols of fuel			
						$\text{lbs of fuel burned} \cdot \text{Wt of products/lb of fuel}$			
						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)	0.06111197			8.89			
Water	(= moles of water in fuel + moles of water in combustion air)	0.12135937			17.64			
Oxygen		0.01027882			1.49			
Nitrogen		0.49523928			71.98			
Sulfur Dioxide		0			0			
Total		0.68800944			100.00			
Boiler	Efficiency	Calculations						
These calculations are based on ASME PTC 4, using heat loss method								
1. Pounds of dry gas per pound of "as fired" composite fuel								
Wg =	$((c\% \cdot d.b.) \cdot \text{Efficiency}) \cdot (44.01 (\text{CO}_2) + 32.00 (\text{O}_2) + 28.02 (\text{N}_2) + (28.01 (\text{CO}) / 12.01 (\text{CO}_2 + \text{CO})) + 12.01 (\text{S}) / 32.07$							
	$\text{lb/lb of as fired fuel}$							
1. Heat loss due to dry gas (%)	$\text{Lwg} = \text{Wg} \cdot 0.24 \cdot (359.75 / \text{HHV}) \cdot 100$							
2. Heat loss due to unburned carbon								
Luc =	% Carbon in the "as fired fuel" $\cdot (1 - \text{Comb. Efficiency}) \cdot 14,500$							
3. Heat loss due to unburned carbon in dust								
4. Heat loss due to moisture in "as Fired Fuel"								
Lmf =	Moisture in fuel (lb/lb of fuel) $\cdot \text{latent heat of vapor at gas leaving temp}$ + Moisture in fuel (lb/lb of fuel) $\cdot \text{latent heat of vapor at inlet temp} / \text{HHV} \cdot 100$							
5. Heat loss due to moisture produced from burning hydrogen in fuel								

[illegible]

	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 (Pslg)	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						

43					
44					
45					
46	Date of Operation	8/9/95am			
47					
48					
49					
50					
51	Boiler Operating Conditions				
52					
53					
54	Total Firing Rate				
55	Gas Support (%)				
56	Excess air used (%)				
57					
58	Actual mass of products of combustion =				
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 (%)				
70	2. Heat loss due to unburned carbon				
71	3. Heat loss due to unburned carbon in dust				
72	4. Heat loss due to moisture in "as Fired Fuel"				
73	5. Heat loss due to moisture produced from burning hydrogen in fuel				
74	6. Heat loss due to moisture in combustion air				
75	7. Heat loss due to formation of carbon monoxide				
76	8. Heat loss due to radiation				
77	9. Heat loss due to steam drum blowdown				
78	Total Losses				
79	Heat Credits				
80	1. Heat supplied by duct burner to entering air				
81	2. Heat supplied by mill to primary (transport) air				
82					
83	BOILER EFFICIENCY (%)				
84					
85					
Summary of Boiler Performance					
C					
D					
E					
F					

	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) =										
15					0.04439078						
16											
17											
18	Determination of Percent Gas Support										
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140		As Fired Coal Composition (Wt)		"As Fired" Fuel (coal+nat. gas) Composition (Wt%)					
23	Coal Heat Input(Btu/h)	16431960		Carbon	78.66	Carbon	78.66				
24				Hydrogen	5.05	Hydrogen	5.05				
25	Gas Heat Input (Btu/h)	0		Nitrogen	1.35	Nitrogen	1.35				
26	Total Firing Rate	16431960		Sulfur	0.74	Sulfur	0.74				
27	Gas Calorific Value (Btu/lb)	23346		Oxygen	5.39	Oxygen	5.39				
28	Gas Firing Rate (lb/h)	0		Ash	4.37	Ash	4.37				
29	Gas Support (% of Heat)	0.00		Moisture	4.45	Moisture	4.45				
30	Fraction of coal	1		Total	100.00	Total	100.00				
31	Fraction of GAS	0									
32				HHV	14414	HHV	14414				
33				Dry ash%	4.57	Dry Ash	4.57				
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							
47	Hydrogen= %H/(100*2)*0.5 mole =			0.0655473 moles							
48	Sulfur= %S/(100*32) *1 mole =			0.01263649 moles							
49				0.00022992 moles							
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 =			0.36537922 moles/lb of as fired fuel							
54											
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)			= 100(O ₂ -C _O)/C _O = 100(0.264-0.264)/0.264 =		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)=			lbs of dry air * 1.0013		13.0817117					
64											
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=					14.0817117 lb/lb of fuel					
67											
68	Actual weight of products =			lbs of fuel burned * Wt of Products/lb of fuel		16053.1514 lb of flue gas					
69											
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 Composition (%)			Dry Flue Gas Comp. (%)		
6	Water	(moles of water in fuel +moles of water in combustion air)			14.42			15.39		
7				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 4.1 using 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 (Enthalpy 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	Lm/h=	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/(CO ₂ +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; Xler 325 acfm; O2 2.7%			
4	Pressures and Temperatures		Steam Data			
5						
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 Givg 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				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	0.04056620		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(O ₂ -C _O /2)/(0.264*N ₂ -(O ₂ -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)							
6	Water		(moles of water in fuel + moles of water in combustion air)	0.0655473	15.02					
7										
8	Oxygen			0.02864977	6.56					
9	Nitrogen			0.01103183	2.53					
10	Sulfur Dioxide			0.33107748	75.84					
11	Total			0.00022992	0.05266852					
12				0.43653629	100.00					
13										
14	Boiler									
15			Efficiency							
16			Calculations							
17			These calculations are based on ASME PTC 4.1 using heat loss method							
18			1. Pounds of dry gas per pound of "as fired" composite fuel							
19										
20			$Wg' = ((c\% d.b) \cdot C.Efficiency) \cdot (44.01 (CO_2) + 32.00 (O_2) + 28.02 (N_2) + (28.01 (CO) / 12.01 (CO_2 + CO)) + 12.01 (S) / 32.07$							
21										
22			11.85622748 lb/lb of as fired fuel							
23										
24			1. Heat loss due to dry gas (%)							
25			$Lwg' = Wg' \cdot 0.24 \cdot (359.75 / HHV \cdot 100$							
26										
27			2. Heat loss due to unburned carbon							
28										
29			$Luc = \% \text{ Carbon in the "as fired Fuel"} \cdot (1 - \text{Comb Efficiency}) \cdot 14,500$							
30										
31										
32			3. Heat loss due to unburned carbon in dust							
33										
34										
35			4. Heat loss due to moisture in "as fired fuel"							
36										
37			$Lmf = \text{Moisture in Fuel (Enthalpy of vapor at gas leaving temp - Enthalpy of water at mill inlet)} / HHV \cdot 100$							
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	AA
43	Lmfl=	8.936 *% hydrogen in "as fired" fuel" (Enthalpy of vapor leaving air heater- Enthalpy of water at mill inlet temp)/HHV								
44										
45										
46	Heat loss due to moisture in combustion air									
47	Theoretical lb of air required for complete combustion/lb of "as fired" fuel						0.16			
48										
49										
50										
51										
52	Actual dry air =									
53										
54	Moisture in air =									
55	Lma =									
56										
57										
58										
59	Heat loss due to formation of carbon monoxide									
60	Lco =						0.05			
61										
62										
63	Heat loss due to radiation									
64							1.29			
65										
66										
67										
68	Total Losses (%)						14.22 %			
69	HEAT CREDITS									
70										
71	Heat supplied by duct burner to entering air									
72	Heat supplied by mill to primary (transport) air									
73										
74	Boiler Efficiency (%)=									
75										
76										
77	Combustion Air Flow (lb/hr)=									
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						

43					
44					
45					
46	Date of Operation	23-Aug			
47					
48					
49					
50					
51	Boiler Operating Conditions				
52					
53					
54	Total Firing Rate				
55	Gas Support (%)				
56	Excess air used (%)				
57					
58	Actual mass of products of combustion =				
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 (%)				
70	2. Heat loss due to unburned carbon				
71	3. Heat loss due to unburned carbon in dust				
72	4. Heat loss due to moisture in "as Fired Fuel"				
73	5. Heat loss due to moisture produced from burning hydrogen in fuel				
74	6. Heat loss due to moisture in combustion air				
75	7. Heat loss due to formation of carbon monoxide				
76	8. Heat loss due to radiation				
77	9. Heat loss due to steam drum blowdown				
78	Total Losses				
79	Heat Credits				
80	1. Heat supplied by duct burner to entering air				
81	2. Heat supplied by mill to primary (transport) air				
82					
83	BOILER EFFICIENCY (%)				
84					
85					
Summary of Boiler Performance					
C					
D					
E					
F					

	G	H	I	J	K	L	M	N	O	P	Q
1				Boiler Performance Calculations							
2											
3											
4											
5	Conversion of Gas Composition from Volume % to Wt%										
6	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%)	
7	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
8	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
9	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
10	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
11	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
12	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
13	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
14	Total	100									
15			Density of N. gas (lb/cu.ft) =		0.04439078						
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	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			0.36176736	moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)		= $100 \times (O_2 - C) / (0.264 \times N_2 - (O_2 - CO_2))$			18.75					
59											
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% RH and 80°F)=										
64											
65				lbs of dry air * 1.0013		12.89159					
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67											
68	Actual weight of products =			lbs of fuel burned * Wt of Products/lb of fuel		13.89159	lb/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											

Calculation of Theoretical Composition of Products

	R	S	T	U	V	W	X	Y	Z	AA
43	Lm/h=	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	=		10.50	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		19.0lb/min coal; Prim. 100%, Sec. 100%, Tert. 50%; Coal gun -10.5", Gas Gun -9"; Xler 380 acfm; O2 3.75%				
4	Pressures and Temperatures		Steam Data			
5						
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											
5	Conversion of Gas Composition from Volume % to Wt%										
6	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%)		
7	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
8	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
9	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
10	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
11	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
12	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
13	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
14	Total	100									
15			Density of N. gas (lb/cu.ft) =		0.04439078						
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 (%)		= 100(O ₂ -CO ₂)/(0.261*N ₂ -(O ₂ -CO ₂))=			21.21					
59											
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 =		0.44289474					
62						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		13.2908109					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67						14.2908109	lb/lb of fuel				
68	Actual weight of products =										
69				lbs of fuel burned * Wt of Products/lb of fuel		16291.5245	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	Carbon Dioxide									
5	Water	(=moles of carbon /lb of fuel)								
6		(moles of water in fuel + moles								
7		of water in combustion air)								
8	Oxygen									
9	Nitrogen									
10	Sulfur Dioxide									
11	Total									
12										
13										
14	Boiler	Efficiency	Calculations							
15										
16	These calculations are based on ASME PTC 4, using 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								
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500								
30										
31										
32	3. Heat loss due to unburned carbon in dust									
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"									
36										
37	Lmf =	Moisture in Fuel (Enthalpy 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									
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmth=	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										
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								
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									
60	Lco =	CO/(CO2+CO)*10160 * Combustion Efficiency* % carbon in "as fired" fuel					0.05			
61										
62										
63	8. Heat loss due to radiation									
64			10 exp (0.62-0.42log Q)				1.29			
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									
73										
74	Boiler Efficiency (%)=									
75							84.70 %			
76										
77	Combustion Air Flow (lb,hr)=									
78							14849 lb/h			
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)	344.9		
7	Feed Water Temperature (°F)	207.2	Enthalpy of Feed Water (Btu/lb)	175.3	(Sat. liquid @ Feed water temp.)	
8	Steam Quality (% moisture)	99.3	Steam Production Rate (PPH)	14,378.5		
9	Gas Temp. Leaving Boiler (°F)	594.2	Blow down Rate (PPH)	2,999.0		
10	Gas Temp. Leaving Air Heater (°F)	399.7	Enthalpy of water vapor at Glvg Temp (Btu/lb)	1,241.6	(Sup. steam @ 1psia&gas lvg temp)	
11	Air Temp Entering Air Heater (°F)	165.9	Enthalpy of water at fuel inlet temp. (Btu/lb)	52.0	(Sat. liq. @ mill inlet temp.)	
12	Air temp leaving Air Pre Heater (°F)	421.1	Enthalpy of vapor at fuel inlet temp. (Btu/lb)	1,096.3	(Sat. vapor @ mill inlet temp.)	
13	Air Temp Entering Boiler (°F)	398.8	Calorimeter Temperature (°F)	301.0		
14	Mill Inlet Temperature (°F)	83.9				
15	Mill air flow rate (lb/h)	1,710.5	Coal Firing Rate (lb/h)	1140	Gas Firing Rate (lb/h)	0
16	Burner Inlet temperature (°F)	184.1	Coal H.H. Value (Btu/lb)	14444	Gas Cal. Value (Btu/lb)	23346
17	FUEL DATA		Coal Moisture Content (%)	3.89		
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 (%)	3.31				
33	Carbon Dioxide (%)	15.30	Ash In Dry Char/Refuse	43.89		
34	Carbon Monoxide (PPM)	178.04	TOTAL CARBON CONVERSION	94.25		
35	Sulfur Dioxide (PPM)	528.92	COAL CARBON CONVERSION	94.25		
36	Oxides of Nitrogen (PPM)	439.46				
37						
38						
39						
40						
41						
42						

A		B	C	D	E	F
Summary of Boiler Performance						
43	Date of Operation	25-Aug				
44						
45						
46						
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				Boiler Performance Calculations							
2											
3											
4											
5	Conversion of Gas Composition from Volume % to Wt%										
6	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%)	
7	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
8	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
9	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
10	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
11	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
12	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
13	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
14	Total	100									
15			Density of N. gas (lb/cu.ft) =		0.04439078						
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	79.20		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(O ₂ -C)/(O ₂ -N ₂ -(O ₂ -C)/2)=								
59						18.16					
60	Actual Dry air Required (moles) = (1+E.A%)* total air required =					0.43076457					
61	Dry air in lbs/lb of "as fired" fuel		= moles of air*29.97 =			12.9100142					
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			12.9267972					
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=										
67						13.9267972 lb/lb of fuel					
68	Actual weight of products =		lbs of fuel burned * Wt of Products/lb of fuel								
69						15876.5489 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									
6	Water									
7		(=moles of carbon /lb of fuel)		0.06600354	14.71					
8	Oxygen	(moles of water in fuel + moles of water in combustion air)		0.02731322	6.09					
9	Nitrogen			0.01389993	3.10					
10	Sulfur Dioxide			0.34123122	76.05					
11	Total			0.00024328	0.05421957					
12				0.4486912	100.00					
13										
14	Boiler									
15		Efficiency	Calculations							
16	These calculations are based on ASME PTC 4.1 using 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								
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500								
30										
31										
32	3. Heat loss due to unburned carbon in dust									
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"									
36										
37	Lmf =	Moisture in Fuel (Enthalpy of vapor at gas leaving temp - Enthalpy of water at mill inlet)/HHV*100								
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	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		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 (Pslg)	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 Givg 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)		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 (%)	3.51				
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		16,518,647.9	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											
2											
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						
7	Ethane	2.48		0.08029	0.04056628						
8	Propane	0		0.1196	0.00199119						
9	Butane	0.43		0.1582	0.00068026						
10	Hydrogen Sulfide	0		0.09109	0						
11	Carbon Dioxide	0		0.117	0						
12	Nitrogen	1.55		0.07439	0.00115305						
13	Total	100									
14											
15											
16											
17											
18											
19											
20											
21											
22	Coal Firing Rate (lb/h)	1140									
23	Coal Heat Input (Btu/h)	16518600									
24											
25	Gas Heat Input (Btu/h)	0									
26	Total Firing Rate	16518600									
27	Gas Calorific Value (Btu/lb)	23346									
28	Gas Firing Rate (lb/h)	0									
29	Gas Support (% of Heat)	0.00									
30	Fraction of coal	1									
31	Fraction of GAS	0									
32											
33											
34											
35											
36											
37											
38											
39											
40											
41											
42											

Boiler Performance Calculations

N. Gas Composition (Wt%, d.b)

Carbon

Hydrogen

Nitrogen

Sulfur

Oxygen

Moisture

Total=

73.40

24.01

2.60

0.00

0.00

0.00

100.00

"As Fired" Fuel (coal+nat. gas) Composition (Wt%)

Carbon

Hydrogen

Nitrogen

Sulfur

Oxygen

Ash

Moisture

Total

79.05

4.93

1.35

0.81

5.24

4.12

4.50

100.00

As Fired Coal Composition (Wt)

Carbon

Hydrogen

Nitrogen

Sulfur

Oxygen

Ash

Moisture

Total

79.05

4.93

1.35

0.81

5.24

4.12

4.5

100.00

Determination of Percent Gas Support

Carbon

Hydrogen

Nitrogen

Sulfur

Oxygen

Ash

Moisture

Total

79.05

4.93

1.35

0.81

5.24

4.12

4.5

100.00

HHV

Dry ash%

	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-C)/2)/(0.261*N2-(O2-C)/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											
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel=					14.1197351	lb/lb of fuel				
67											
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	Carbon Dioxide	(=moles of carbon /lb of fuel) (moles of water in fuel +moles of water in combustion air)	0.06587908	14.46					
5	Water		0.02808531	6.17					
6	Oxygen		0.01499689	3.29					
7	Nitrogen		0.3463104	76.02					
8	Sulfur Dioxide		0.00025367	0.05568776					
9	Total		0.45552535	100.00					
10									
11									
12									
13									
14	Boiler	Efficiency							
15		Calculations							
16	These calculations are based on ASME PTC 4.1 using heat loss method								
17									
18	1. Pounds of dry gas per pound of "as fired" composite fuel								
19									
20	Wg' =								
21									
22									
23									
24	1. Heat loss due to dry gas (%)								
25									
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =								
30									
31									
32	3. Heat loss due to unburned carbon in dust								
33									
34									
35	4. Heat loss due to moisture in "as fired fuel"								
36									
37	Lmf =								
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	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/(CO ₂ +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/mln 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	Volatiles 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
Summary of Boiler Performance						
43						
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					
81	2. Heat supplied by mill to primary (transport) air					
82						
83	BOILER EFFICIENCY (%)					
84				84.79		
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(O ₂ -C _O /2)/(0.261*N ₂ -(O ₂ -C _O /2))=			19.83					
59											
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 =		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										
5	Carbon Dioxide		(=moles of carbon /lb of fuel)	0.06587219	14.43			Dry Flue Gas Comp. (%)		
6	Water		(moles of water in fuel + moles of water in combustion air)					15.37		
7										
8	Oxygen			0.02809064	6.15			0.00		
9	Nitrogen			0.01523345	3.34			3.55		
10	Sulfur Dioxide			0.34717007	76.03			81.01		
11	Total			0.00025365	0.05554845			0.06		
12				0.45661998	100.00			100.00		
13										
14	Boiler		Efficiency							
15			Calculations							
16	These calculations are based on ASME PTC 4, using heat loss method									
17										
18	1. Pounds of dry gas per pound of "as fired" composite fuel									
19										
20	Wg =		$((c\% \text{ d.b.}) \cdot C \cdot \text{Efficiency}) \cdot (44.01 \text{ (CO}_2) + 32.00 \text{ (O}_2) + 28.02 \text{ (N}_2) + (28.01 \text{ (CO)} / 12.01 \text{ (CO}_2 + \text{CO})) + 12.01 \text{ (S)} / 32.07$							
21										
22			12.50466265 lb/lb of as fired fuel							
23										
24	1. Heat loss due to dry gas (%)		$L_{wg} = W_g \cdot 0.24 \cdot (359.75) / \text{HHV} \cdot 100$							
25										
26										
27	2. Heat loss due to unburned carbon									
28										
29	Luc =		% Carbon in the "as fired Fuel" $\cdot (1 - \text{Comb. Efficiency}) \cdot 14,500$							
30										
31										
32	3. Heat loss due to unburned carbon in dust									
33										
34										
35	4. Heat loss due to moisture in "as fired fuel"									
36										
37	Lmf =		Moisture in Fuel (Enthalpy of vapor at gas leaving temp. - Enthalpy of water at mill inlet) / HHV $\cdot 100$							
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	AA
43	Lm/h=	8.936 % hydrogen in "as fired" fuel* (Enthalpy of vapor leaving air heater - Enthalpy of water at mill inlet temp)/t-HV								
44										
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									
48	=						0.16			
49										
50										
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								
55	Lma =	moisture in air * (enthalpy of water vapor leaving air heater - enthalpy of vapor at mill inlet temp.)								
56										
57										
58										
59	7. Heat loss due to formation of carbon monoxide									
60	Lco =	CO/(CO ₂ +CO)*10160 * Combustion Efficiency* % carbon in "as fired" fuel					0.06			
61										
62										
63	8. Heat loss due to radiation									
64							1.28			
65										
66										
67										
68	Total Losses (%)									
69	HEAT CREDITS						15.18 %			
70										
71	1. Heat supplied by duct burner to entering air									
72	2. Heat supplied by mill to primary (transport) air									
73										
74	Boiler Efficiency (%)=									
75										
76										
77	Combustion Air Flow (lb/hr)=									
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											
5	Conversion of Gas Composition from Volume % to Wt%										
6	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%)	
7	Methane	95.54		0.04246	0.04056628		Carbon	73.40		73.3583626	
8	Ethane	2.48		0.08029	0.00199119		Hydrogen	24.01		23.9954486	
9	Propane	0		0.1196	0		Nitrogen	2.60		2.59618878	
10	Butane	0.43		0.1582	0.00068026		Sulfur	0.00		0	
11	Hydrogen Sulfide	0		0.09109	0		Oxygen	0.00		0	
12	Carbon Dioxide	0		0.117	0		Moisture	0.00		0.05	
13	Nitrogen	1.55		0.07439	0.00115305		Total=	100.00		100.00	
14	Total	100									
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)	16518600		As Fired Coal Composition (Wt)		"As Fired" Fuel (coal+nat. gas) Composition (Wt%)					
24				Carbon	79.18	Carbon	79.18				
25	Gas Heat Input (Btu/h)	0		Hydrogen	4.94	Hydrogen	4.94				
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	5.25	Oxygen	5.25				
29	Gas Support (% of Heat)	0.00		Ash	4.12	Ash	4.12				
30	Fraction of coal	1		Moisture	4.35	Moisture	4.35				
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											
46	Carbon = $\%C/(100 \cdot 12) \cdot 1 \text{ mole} =$			Theoretical Oxygen Requirement							
47	Hydrogen = $\%H/(100 \cdot 2) \cdot 0.5 \text{ mole} =$			0.06598256 moles							
48	Sulfur = $\%S/(100 \cdot 32) \cdot 1 \text{ mole} =$			0.01233885 moles							
49				0.00025407 moles							
50	Oxygen required = Sum of the 3			0.07857548 moles							
51	Oxygen available in the Fuel = $\%O/(100 \cdot 32)$			0.001641							
52	Net Oxygen required =			0.07693448 moles							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =			0.36635468 moles/lb of as fired fuel							
54											
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)					21.60					
59											
60	Actual Dry air Required (moles) = $(1+E.A\%) \cdot \text{total air required} =$					0.44548656					
61	Dry air in lbs/lb of "as fired" fuel					13.3512323					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H. and 80°F) =					13.3685889					
64											
65											
66	Weight of products of combustion = Actual wet air used + weight of fuel =										
67											
68	Actual weight of products =					14.3685889 lb/lb of fuel					
69						lbs of fuel burned $\cdot$ Wt of Products/lb of fuel					
70						16380.1913 lb of fluo 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										
5	Carbon Dioxide	(=moles of carbon /lb of fuel) (moles of water in fuel +moles of water in combustion air)		0.06598256	Wet Flue Gas Composition (%)			Dry Flue Gas Comp. (%)		
6	Water				14.23			15.14		
7				0.02805862	6.05			0.00		
8	Oxygen			0.01661769	3.58			3.81		
9	Nitrogen			0.35206159	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, using 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									
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"									
36										
37	Lmf=	Moisture in Fuel (Enthalpy 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									
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lmth=	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)		Gas Analysis (Dry Vol%)	
20	Volatile Matter (Wt%)	30.82				
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						

	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					"As Fired" Fuel (coal+nat. gas) Composition (Wt%)				
23	Coal Heat Input(Btu/h)	16518600		As Fired Coal Composition (Wt)			Carbon	81.30			
24				Carbon	81.30		Hydrogen	5.07			
25	Gas Heat Input (Btu/h)	0		Hydrogen	5.07		Nitrogen	1.38			
26	Total Firing Rate	16518600		Nitrogen	1.38		Sulfur	0.83			
27	Gas Calorific Value (Btu/lb)	23346		Sulfur	0.83		Oxygen	5.39			
28	Gas Firing Rate (lb/h)	0		Oxygen	5.39		Ash	4.23			
29	Gas Support (% of Heat)	0.00		Ash	4.23		Moisture	1.79			
30	Fraction of coal	1		Moisture	1.79		Total	100.00			
31	Fraction of GAS	0		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 (%)		= $100(O_2 - C(O_2))/(0.264 \cdot N_2 - (O_2 - C(O_2)))$			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											
70					16477.6468	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									
5	Carbon Dioxide	(=moles of carbon /lb of fuel)							
6	Water	(moles of water in fuel +moles of water in combustion air)	0.06774853	Wet Flue Gas Composition (%)					
7				14.55					
8	Oxygen		0.02730305	5.86					
9	Nitrogen		0.01515683	3.26					
10	Sulfur Dioxide		0.35511209	76.27					
11	Total		0.00026087	0.05603109					
12			0.46558137	100.00					
13									
14	Boiler	Efficiency							
15		Calculations							
16	These calculations are based on ASME PTC 4 using 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							
25									
26									
27	2. Heat loss due to unburned carbon								
28									
29	Luc =	% Carbon in the "as fired Fuel" * (1-Comb.Efficiency) * 14,500							
30									
31									
32	3. Heat loss due to unburned carbon in dust								
33									
34									
35	4. Heat loss due to moisture in "as Fired Fuel"								
36									
37	Lmf=	Moisture in Fuel (Enthalpy 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								
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										

[illegible]

	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			3.70		
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						

	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)	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							
47	Hydrogen= %H/(100*2) * 0.5 mole =			0.06786219 moles							
48	Sulfur= %S/(100*32) * 1 mole =			0.01292731 moles							
49				0.00026053 moles							
50	Oxygen required= Sum of the 3										
51	Oxygen available in the Fuel= %O/(100*32)			0.08105003 moles							
52	Net Oxygen required =			0.00190746							
53	Theoretical Dry Air for Combustion = Net Oxygen required/0.21 =			0.07914257 moles							
54				0.37686938 moles/lb of as fired fuel							
55											
56	Calculation of Products of combustion										
57											
58	Excess air used (%)					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					13.5084426					
62											
63	Actual wet air used/lb of "as fired" fuel (assuming 60% R.H and 80°F)=					13.5260036					
64											
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 =										
69						lbs of fuel burned * Wt of products/lb of fuel					
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										
5	Carbon Dioxide	(=moles of carbon /lb of fuel)		0.06786219	Wet Flue Gas	Composition (%)		Dry Flue Gas	Comp. (%)	
6	Water	(moles of water in fuel +moles of water in combustion air)			14.50			15.40		
7				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 4.1 using 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									
33										
34										
35	4. Heat loss due to moisture in "as Fired Fuel"									
36										
37	Lmf=	Moisture in Fuel (Enthalpy 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									
42										

	R	S	T	U	V	W	X	Y	Z	AA
43	Lm/h=	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)=						14555	lb/h		
78										
79										
80										
81										
82										
83										
84										
85										