ABMA
American Boiler Manufacturers Association
1500 Wilson Boulevard
Arlington VA 22209

DoE
United States Department of Energy
Division of Power Systems
Energy Technology Branch
Washington DC 20545

EPA
U.S. Environmental Protection Agency
Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park NC 27711

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April 1980

Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement - Site G

Interagency Energy/Environment R&D Program Report

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This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

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April 1980

Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement - Site G

by

P.L. Langsjoen, J.O. Burlingame,
and J.E. Gabrielson

KVB, Inc.
6176 Olson Memorial Highway
Minneapolis, Minnesota 55422

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Project Officers: R.E. Hall (EPA) and W.T. Harvey, Jr. (DoE)

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

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and

AMERICAN BOILER MANUFACTURERS ASSOCIATION
1500 Wilson Boulevard
Arlington, VA 22209

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R. D. Bessette	Island Creek Coal Company
T. Davis	Combustion Engineering
N. H. Johnson	Detroit Stoker
K. Luuri	Riley Stoker
D. McCoy	E. Keeler Company
J. Mullan	National Coal Association
E. A. Nelson	Zurn Industries
E. Poitras	The McBurney Corporation
P. E. Ralston	Babcock and Wilcox
D. C. Reschley	Detroit Stoker
R. A. Santos	Zurn Industries

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Finally, our gratitude goes to the host boiler facilities which invited us to test their boiler. At their request, the facilities will remain anonymous to protect their own interests. Without their cooperation and assistance this program would not have been possible.

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1.0 INTRODUCTION

The principal objective of the test program described in this report, one of several reports in a series, is to produce information which will increase the ability of boiler manufacturers to design and fabricate stoker boilers that are an economical and environmentally satisfactory alternative to oil-fired units. Further objectives of the program are to: provide information to stoker boiler operators concerning the efficient operation of their boilers; provide assistance to stoker boiler operators in planning their coal supply contracts; refine application of existing pollution control equipment with special emphasis on performance; and contribute to the design of new pollution control equipment.

In order to meet these objectives, it is necessary to define stoker boiler designs which will provide efficient operation and minimum gaseous and particulate emissions, and define what those emissions are in order to facilitate preparation of attainable national emission standards for industrial size, coal-fired boilers. To do this, boiler emissions and efficiency must be measured as a function of coal analysis and sizing, rate of flyash reinjection, overfire air admission, ash handling, grate size, and other variables for different boiler, furnace, and stoker designs.

A field test program designed to address the objectives outlined above was awarded to the American Boiler Manufacturers Association (ABMA), sponsored by the United States Department of Energy (DOE) under contract number EF-77-C-01-2609, and co-sponsored by the United States Environmental Protection Agency (EPA) under inter-agency agreement number IAG-D7-E681. The program is directed by an ABMA Stoker Technical Committee which, in turn, has subcontracted the field test portion to KVB, Inc., of Minneapolis, Minnesota.

This report is the Final Technical Report for the seventh of eleven boilers to be tested under the ABMA program. It contains a description of the facility tested, the coals fired, the test equipment and procedures, and the results and observations of testing. There is also a data supplement to this report containing the "raw" data sheets from the tests conducted. The data supplement has the same EPA report number as this report except that it is followed by "b" rather than "a". As a compilation of all data obtained at this test site, the supplement acts as a research tool for further data reduction and analysis as new areas of interest are uncovered in subsequent testing.

At the completion of this program, a Final Technical Report will combine and correlate the test results from all sites tested. A report containing operating guidelines for boiler operators will also be written, along with a separate report covering trace species data. These reports will be available to interested parties through the National Technical Information Service (NTIS) or through the EPA's Technical Library.

Although it is EPA policy to use S.I. units in all EPA sponsored reports, an exception has been made herein because English units have been conventionally used to describe boiler design and operation. Conversion tables are provided in the Appendix for those who prefer S.I. units.

To protect the interests of the host boiler facilities, each test site in this program has been given a letter designation. As the seventh site tested, this is the Final Technical Report for Test Site G under the program entitled, "A Testing Program to Update Equipment Specifications and Design Criteria for Stoker Fired Boilers."

2.0 EXECUTIVE SUMMARY

A coal fired spreader stoker rated at 75,000 lbs steam/hour was extensively tested for emissions and efficiency between February 10 and March 25, 1979. This section summarizes the results of these tests and provides references to supporting figures, tables and commentary found in the main text of the report.

UNIT TESTED: Described in Section 3.0, page 11.

- Zurn Boiler

  Built 1974
  Type V.C. 2 drum
  75,000 lbs/hr rated capacity
  140 psig operating steam pressure
  Saturated steam

- Zurn Stoker

  Spreader with 3 feeders
  Traveling grate with front ash discharge
  Flyash reinjection from boiler hopper only
  Two rows OFA on back water wall and one row on front

COALS TESTED: Described in Section 3.6, page 17, and Section 5.4, page 72.

- White Ash Coal

  12,869 Btu/lb
  8.05% Ash
  0.78% Sulfur
  4.56% Moisture
  2700+°F Initial ash deformation temperature

- Spurlock Coal

  13,860 Btu/lb
  4.42% Ash
  1.31% Sulfur
  3.02% Moisture
  2420°F Initial ash deformation temperature

O Pevler Coal

12,832 Btu/lb
7.32% Ash
0.76% Sulfur
4.59% Moisture
2700+°F Initial ash deformation temperature

OVERFIRE AIR TEST RESULTS: Overfire air pressure was varied from 23" H_2O pressure (baseline) to as low as 12" H_2O pressure (low) in two test sets with the boiler operating at its design capacity. Overfire air flow rate was also measured and related to static pressure. The test results follow (Section 5.1, page 39, Table 5-1, page 40.

O Particulate Loading

Conflicting trends were observed for particulate loading vs OFA in the two test sets. The variations were interpreted as normal data scatter and unrelated to OFA conditions (Section 5.1.1, page 39, Table 5-2, page 41).

O Nitric Oxide

Conflicting trends were observed for nitric oxide concentration vs OFA in the two test sets. The variations were interpreted as normal data scatter and unrelated to OFA conditions. (Section 5.1.2, page 41, Table 5-3, page 41).

O Boiler Efficiency

Boiler efficiency was highest at low OFA in both test sets. It is reasoned that these efficiency variations were unrelated to OFA conditions because flyash combustibles were not significantly changed (Section 5.1.3, page 42, Table 5-4, page 42).

O Overfire Air Flow Rate

Overfire air was found to constitute 10% of the furnace combustion air. Eighty-five percent of the overfire air is introduced through the back wall. The overfire air flow (lbs/hr) and overfire air static pressure ("H_2O) relationship for each row of jets is presented. (Section 5.1.4, page 42, Figures 5-1 and 5-2, pages 43 and 46, Table 5-5, page 45).

O Carbon Monoxide

No data is available because the carbon monoxide gas analyzer was out of service during Testing at Site G.

FLYASH REINJECTION: Boiler G pneumaticall reinjects flyash from the boiler hopper. There is no reinjection from the dust collector. During one test the boiler hopper ash was diverted to barrels. The results of this test follow (Section 5.2, page 47).

0 Particulate Loading

Reduced reinjection resulted in a 14% drop in particulate mass loading at the boiler outlet (Table 5-6, page 47).

0 Boiler Efficiency

The boiler hopper ash represents a 1.1% potential efficiency gain when reinjected. Thus boiler efficiency was assumed to drop by this amount when reinjection was stopped. Percent combustibles in the ash was higher during the non-reinjection test. (Table 5-7, page 48).

BOILER EMISSION PROFILES: Boiler emissions and efficiency were measured over the load range 16% to 102% of design capacity which corresponds to a grate heat release range of 130,000 to 830,000 Btu/hr-ft^2. Measured oxygen levels ranged from 4.1 to 15.2% (Section 5.3, page 48).

0 Excess Oxygen Operating Levels

At full load, the unit was normally operated in the range 6.5 to 7.5% O_2 (42 to 53% excess air). Oxygen increased as load decreased such that 14.6 to 15.2% O_2 (205 to 241% excess air) was used at the very low loads of 16-17% capacity. Manufacturers predicted performance was based on 31% excess air at full load (Section 5.3.1, page 48, Figure 5-3, page 49).

0 Particulate Loading

At full load and normal operating conditions the boiler outlet particulate loading ranged from 2.93 to 6.79 lbs/10^6Btu and averaged 5.09 lbs/10^6 Btu. After the mechanical dust collector the full load particulate loading ranged from 0.17 to 0.36 lbs/10^6Btu and averaged 0.28 lbs/10^6Btu. The average ash carryover was 41% at the high loads and 25% at the lowest loads. Swing load conditions produced 60% higher particulate emissions than base load conditions (Section 5.3.2, page 50, Figures 5-4, 5-5, pages 51, 53, Table 5-8, page 52).

o Nitrogen Oxides

Nitric oxide (NO) averaged 0.49 lbs/10^6Btu (360 ppm) at full load and 0.51 lbs/10^6Btu (379 ppm) at 80% and 17% of capacity. Nitric oxide increased by 0.046 lbs/10^6Btu for each one percent increase in oxygen at constant load. Nitrogen dioxide (NO_2) concentrations were negligible (Section 5.3.3, page 52, Figures 5-6 through 5-11, pages 55-60, Table 5-9, page 54).

o Hydrocarbons

Hydrocarbons (HC) showed signs of decreasing with decreasing load, averaging 33 ppm at full capacity and 22 ppm at 80% capacity. Hydrocarbon concentrations also decreased as oxygen increased at 80% load (Section 5.3.4, page 61, Figures 5-12 and 5-13, pages 62 and 63).

o Combustibles in the Ash

The combustible content of the flyash and bottom ash was slightly higher at high loads than at low loads. No trend with oxygen was observed. Bottom ash averaged 10% combustible. Combustible contents of the flyash averaged 53% at the boiler outlet, 32% at the dust collector outlet, and 54% in the dust collector hopper (Section 5.3.5, page 61, Figures 5-14 through 5-17, pages 64, 65, 66 and 67).

BOILER EFFICIENCY: Measured boiler efficiency was several percent lower than the manufacturer's predicted efficiency because the unit was operated at a higher than predicted excess air. Boiler efficiencies averaged 75.8% at full capacity (77.0% predicted), 74.5% at 80% capacity (79.2% predicted) and 65.5% at 17% capacity (Section 5.3.6, page 68, Figure 5-18, page 69, Tables 5-10, 5-11, 5-12, pages 68, 70, 71).

COAL PROPERTIES: Three coals were test fired. Proximate analysis and size consistency were determined for coal samples from most tests. Ultimate and mineral analysis were determined for selected tests (Section 5.4, page 72).

o Chemical Analysis

White Ash and Pevler coals were very similar. Spurlock coal was lower in both moisture and ash, and higher in sulfur content (Section 5.4.1, page 72, Tables 5-13 through 5-17, pages 72-76).

0 Coal Size Consistency

Pevler A coal had the lowest percentage of fines at an average 22%. Blend coal had 41% fines and Pevler B coal had 36% fines. The coal size consistency of all three coals was within the ABMA recommended limits for spreader stokers. (Section 5.4.2, page 77, Table 5-18, page 78, Figures 5-19, 5-20, 5-21, pages 79, 80, 81).

0 Effect on Emissions and Efficiency

The low ash low fines Pevler A coal produced the lowest particulate loadings at full load. Nitric oxide emissions were similar for all three coals. Sulfur dioxide was proportional to sulfur content of coal. Sulfur retention in the ash was 3.5 to 6.0% of the fuel sulfur. Pevler A coal had the lowest combustible fraction in the bottom ash but the highest combustible fraction in the dust collector outlet flyash. Pevler A coal gave the highest boiler efficiency because of its low combustible heat loss. (Section 5.4.3, page 77).

<u>PARTICLE SIZE DISTRIBUTION OF FLYASH:</u> Ten particle size distribution measurements were made at the boiler outlet. Results vary with measurement technique. Pevler B coal produced more fines than either Blend or Pevler A coals (Section 5.5, page 86, Tables 5-23, 5-24, 5-25, pages 87, 88, 92, Figures 5-22, 5-23, 5-24, pages 89, 90, 91).

<u>EFFICIENCY OF MULTICLONE DUST COLLECTOR:</u> The collection efficiency of the mechanical dust collector averaged 94.4% at loads of 80% and 100% design capacity. Collection efficiency dropped to an average 63.4% at low loads of 17% design capacity (Section 5.6, page 96, Table 5-26, page 94, Figure 5-25, page 92).

<u>SOURCE ASSESSMENT SAMPLING SYSTEM:</u> Flue gas was sampled for polynuclear aromatic hydrocarbons and trace elements during two tests on Blend coal and one test on Pevler B coal. Trace specie data will be presented for all boilers tested in a separate report upon completion of the test program (Section 5.7, page 93, Table 5-27, page 96).

The test plan and the emissions data are summarized in Tables 2-1 and 2-2 on the following pages. Other data tables are included at the end of Section 5.0, Test Results and Observations. For reference, a Data Supplement containing all the unreduced data obtained at Site G is available under separate cover but with the same title followed by the words "Data Supplement," and having the same EPA document number followed by the letter "b" rather than "a". Copies of this report and the Data Supplement are available through EPA and NTIS.

TABLE 2-1

TEST PLAN FOR TEST SITE G

Firing Conditions					Test Measurements					Test No.		
% Boiler Capacity	Load Condition	Excess Air	Overfire Air	Flyash Reinjection	Flue Gas Composition	Part. Loading	SASS	SOx	OFA Flow Rate	White Ash	Spurlock Coal	Pevler Coal
100%	baseline	norm	norm	norm	x	x				5	8	18
100%	baseline	norm	norm	No	x	x				17		
100%	baseline	Vary	norm	norm	x					12		25
80%	baseline	norm	norm	norm	x	x				2		23
80%	baseline	norm	Low	norm	x	x				3		24
80%	baseline	Vary	norm	norm	x					11		26
80%	Swing	norm	norm	norm	x	x				4 & 10		22
80%	Swing	norm	norm	norm	x		x	x		9 & 15		20
60%	baseline	norm	norm	norm	x	x				6		
15%	baseline	norm	norm	norm	x	x				16	7	19
NA	NA	NA	norm	NA					x	13 & 14		
NA	NA	NA	Low	NA					x			20

Note: Normal (norm) Overfire Air is the maximum system output at high loads.

Normal (norm) Flyash Reinjection is from the boiler hopper only.

Flue Gas Composition includes O_2, CO_2 and NO on all tests, NO_2 and HC on selected tests. CO instrument was out of service during testing.

Particulate Loadings were taken simultaneously at boiler outlet (uncontrolled) and at dust collector outlet (controlled).

SASS stands for Source Assessment Sampling System and is used to measure trace elements and organic species in the flue gas, as well as provide a particle size distribution of the flyash.

SOx (SO_2 & SO_3) was measured by the Shell-Emeryville wet chemical method), and by the EPA test method 6.

OFA Flow Rate is a measure of lbs/hr air injected into the furnace above the grate by the overfire air system.

TABLE 2-2

EMISSION DATA SUMMARY
TEST SITE G

Test No.	Date	% Design Capacity	Coal	Excess Air %	O_2 % dry	CO_2 % dry	NO ppm dry	NO $lb/10^6Btu$	NO_2 $lb/10^6Btu$	HC ppm wet	Part. Blr Out $lb/10^6Btu$	Part. D.C. Out $lb/10^6Btu$	Special Tests or Conditions
1	2/10/79	92	W										Aborted Test
2	2/11/79	85	W	69	8.9	10.2	321	0.435	--	--	4.271	0.222	
3	2/11/79	80	W	67	8.7	10.5	380	0.515	--	--	4.332	0.220	Low OFA
4	2/16/79	77	W	94	10.4	9.4	486	0.658	0.000	--	7.408	0.221	
5	2/17/79	102	W	48	7.0	12.0	380	0.515	--	--	6.786	0.274	Brink Impactor
6	2/17/79	57	W	96	10.5	9.4	478	0.647	--	--	4.171	0.129	
7	2/25/79	17	S	205	14.6	4.4	364	0.492	0.000	--	2.139	0.953	
8	2/25/79	100	S	43	6.6	11.6	306	0.414	0.000	--	2.932	0.166	
9	2/28/79	72	W	89	10.2	9.0	330	0.447	--	--	--	--	SASS, SO_x
10	3/02/79	86	W	82	9.7	9.8	442	0.599	0.004	--	6.592	0.484	
11A	3/03/79	78	W	58	8.0	11.0	402	0.544	0.000	19	--	--	
11B	3/03/79	78	W	53	7.6	11.0	458	0.620	0.000	20	--	--	
11C	3/03/79	78	W	44	6.7	12.2	358	0.485	0.000	23	--	--	
11D	3/03/79	78	W	38	6.0	12.8	300	0.406	0.000	24	--	--	
12A	3/03/79	98	W	49	7.2	11.6	418	0.566	0.000	39	--	--	
12B	3/03/79	98	W	46	6.8	12.2	381	0.516	0.000	41	--	--	
12C	3/03/79	98	W	39	6.1	12.4	363	0.492	0.000	35	--	--	
12D	3/03/79	98	W	36	5.8	12.4	320	0.433	0.000	38	--	--	
12E	3/03/79	98	W	29	5.0	13.2	304	0.412	0.000	39	--	--	
13	3/15/79	--	W	--	--	--	--	--	--	--	--	--	OFA Flow Rate
14	3/15/79	--	W	--	--	--	--	--	--	--	--	--	OFA Flow Rate
15	3/16/79	87	W	69	8.7	10.6	457	0.621	0.000	--	--	--	SASS, SO_x
16	3/17/79	16	W	241	15.2	4.6	391	0.529	0.000	--	2.265	0.933	
17	3/17/79	98	W	52	7.4	11.5	397	0.538	0.000	--	5.858	0.364	No Reinj., Brink
18	3/18/79	97	P	53	7.5	11.6	4.5	0.563	0.009	--	4.783	0.320	
19	3/18/79	17	P	230	15.1	4.1	381	0.517	0.000	--	2.057	0.495	
20	3/21/79	78	P	74	9.2	10.4	396	0.536	0.000	--	--	--	SASS, SO_x
21	3/22/79	--	P	--	--	--	--	--	--	--	--	--	OFA Flow Rate
22	3/23/79	82	P	73	9.1	10.3	414	0.561	0.000	--	4.720	0.334	
23	3/24/79	76	P	58	8.0	11.2	423	0.573	0.000	--	4.567	0.320	
24	3/24/79	78	P	51	7.3	11.7	336	0.456	0.000	--	4.003	0.260	Low OFA
25A	3/25/79	100	P	38	6.0	12.8	360	0.488	--	--	--	--	
25B	3/25/79	100	P	36	5.7	13.2	388	0.526	--	--	--	--	
25C	3/25/79	100	P	31	5.2	13.2	353	0.479	--	--	--	--	
25D	3/25/79	100	P	22	4.0	14.2	296	0.401	--	--	--	--	
26A	3/25/79	78	P	59	8.0	11.4	402	0.545	--	--	--	--	
26B	3/25/79	78	P	48	7.0	12.2	348	0.472	--	--	--	--	
26C	3/25/79	78	P	38	6.0	13.2	300	0.407	--	--	--	--	
26D	3/25/79	78	P	31	5.2	13.7	265	0.359	--	--	--	--	

Note: Coal: W-White Ash, S-Spurlock, P-Pevler
SO_2 ($lb/10^6Btu$): Test 9 - 1.198, Test 15 - 1.050, Test 20 - 1.039
SO_3 ($lb/10^6Btu$): Test 9 - 0.010, Test 15 - 0.006, Test 20 - 0.010
Carbon Monoxide not measured because of equipment out-of-service

3.0 DESCRIPTION OF FACILITY TESTED AND COALS FIRED

This section discusses the general physical layout and operational characteristics of the boiler tested at Test Site G. The coals used in this test series are also discussed.

3.1 BOILER DESCRIPTION

Boiler G was built in 1974 by Zurn Industries, Inc., and equipped with a Zurn spreader stoker. The boiler is rated at 75,000 lbs/hr continuous operation at 160 psig saturated steam. As found operating pressure was 140 psig. A boiler schematic is presented in Figure 3-1.

The Zurn Travagrate spreader stoker has three coal feeders and continuous front end ash discharge. The effective area of the grate is 137 ft^2. Design data on the boiler and stoker are presented in Table 3-1. Predicted performance data at various loads are presented in Table 3-2.

3.2 OVERFIRE AIR SYSTEM

The overfire air system consists of a row of lower overfire air jets on the front wall and a row each of upper and lower overfire air jets on the rear wall. There are 12 jets spaced ten inches apart in the front row and 14 jets spaced nine inches apart in back. This configuration is shown in Figure 3-2. Overfire air is supplied by an independent fan, and is not preheated.

3.3 FLYASH REINJECTION

Flyash is pneumatically reinjected from the boiler dust hopper only; through three nozzles which take the place of the number 3, 7, and 12 lower overfire air jets. Figure 3-3 shows this configuration. One test at this site was run without reinjection in an attempt to determine any changes in particulate loading and boiler efficiency due to this variable.

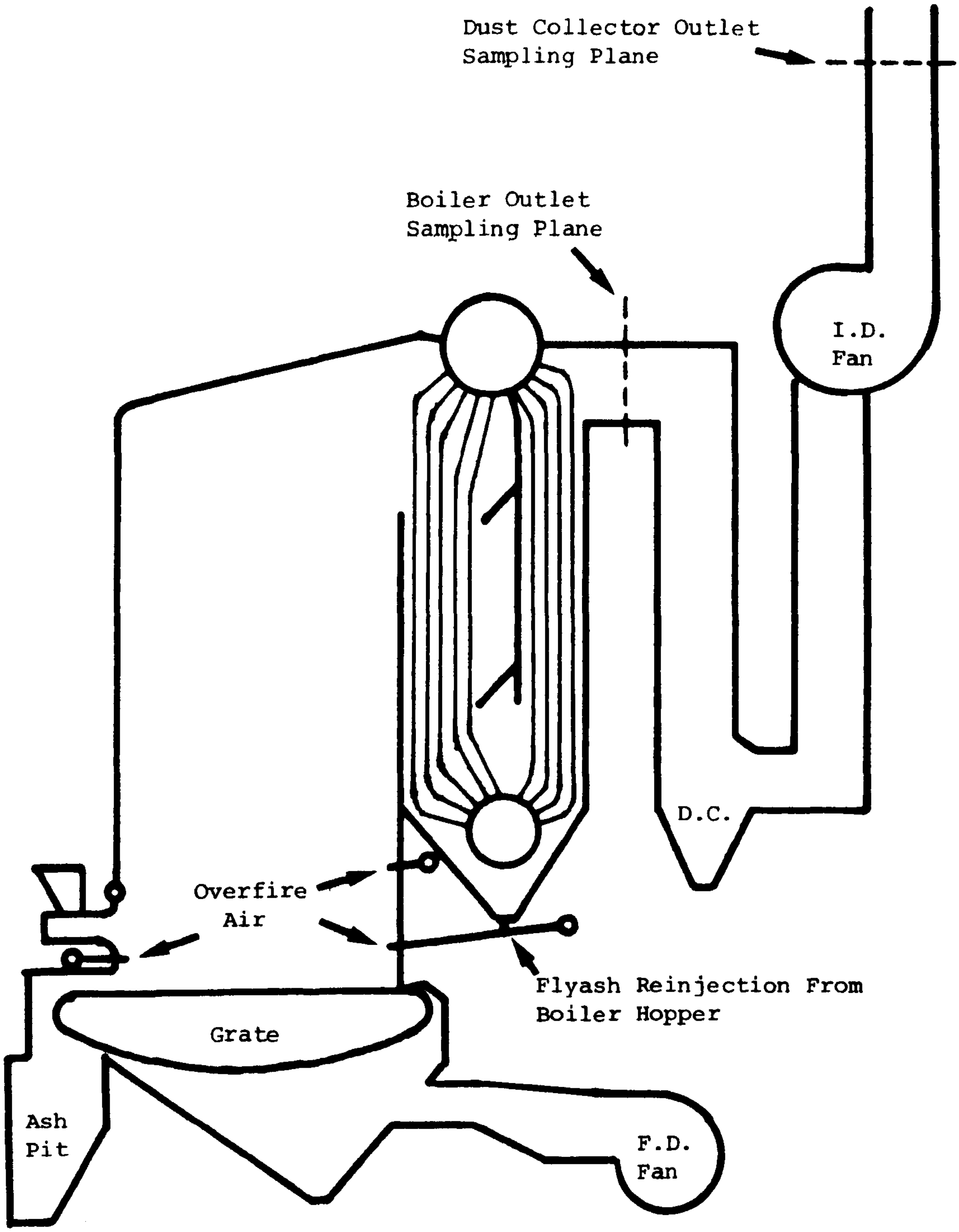


FIGURE 3-1. Schematic of Boiler G

TABLE 3-1

DESIGN DATA
TEST SITE G

BOILER:	Manufacturer	Zurn Industries
	Type	V.C. 2 drum
	Boiler Heating Surface	8,280 ft^2
	Design Pressure	200 psig
	Waterwall Heating Surface	2,140 ft^2
	Feedwater Temperature	212 °F
FURNACE:	Volume	4,100 ft^3
STOKER:	Manufacturer	Zurn Industries
	Type	Spreader
	Grate Type	Traveling Continuous
	Ash Discharge	Front
	Effective Grate Width	9'9"
	Effective Grate Length	14'2"
	Effective Grate Area	137 ft^2
HEAT RATES:	Steam Flow	75,000 lbs/hr
	Input to Furnace	98.95 $x10^6$Btu/hr
	Total Heat Available	88.98 $x10^6$Btu/hr
	Furnace Width Heat Release	10.2 $x10^6$Btu/ft-hr
	Grate Heat Release	714 $x10^3$Btu/ft^2-hr
	Furnace Liberation	24 $x10^3$Btu/ft^3-hr

TABLE 3-2

PREDICTED PERFORMANCE DATA
TEST SITE G

Steam Flow	75,000 lbs/hr
Type of Fuel	Coal
Excess Air Leaving	31 %
Fuel	7.71 $x10^3$lbs/hr
Flue Gas Leaving	103.48 $x10^3$lbs/hr
Combustion Air	93.07 $x10^3$lbs/hr
Drum Pressure	160 psig
Gas Temperature Leaving Furnace	1,815 °F
Gas Temperature Leaving Boiler	530 °F
F.W. to Boiler	212 °F
Furnace Draft Loss	0.15 "H_2O
Boiler Draft Loss	1.35 "H_2O
Burner and Blast Gate D.L.	2.70 "H_2O
Duct Draft Loss	0.25 "H_2O
Damper Draft Loss	0.50 "H_2O
Dry Gas Losses	10.74 %
H_2 and H_2O in Fuel Losses	4.93 %
Moisture in Air Losses	0.27 %
Unburned Combustible Losses	4.95 %
Radiation Losses	0.57 %
Manufacturers Margin	1.50 %
Total Heat Losses	22.96 %
Efficiency of Unit	77.04 %

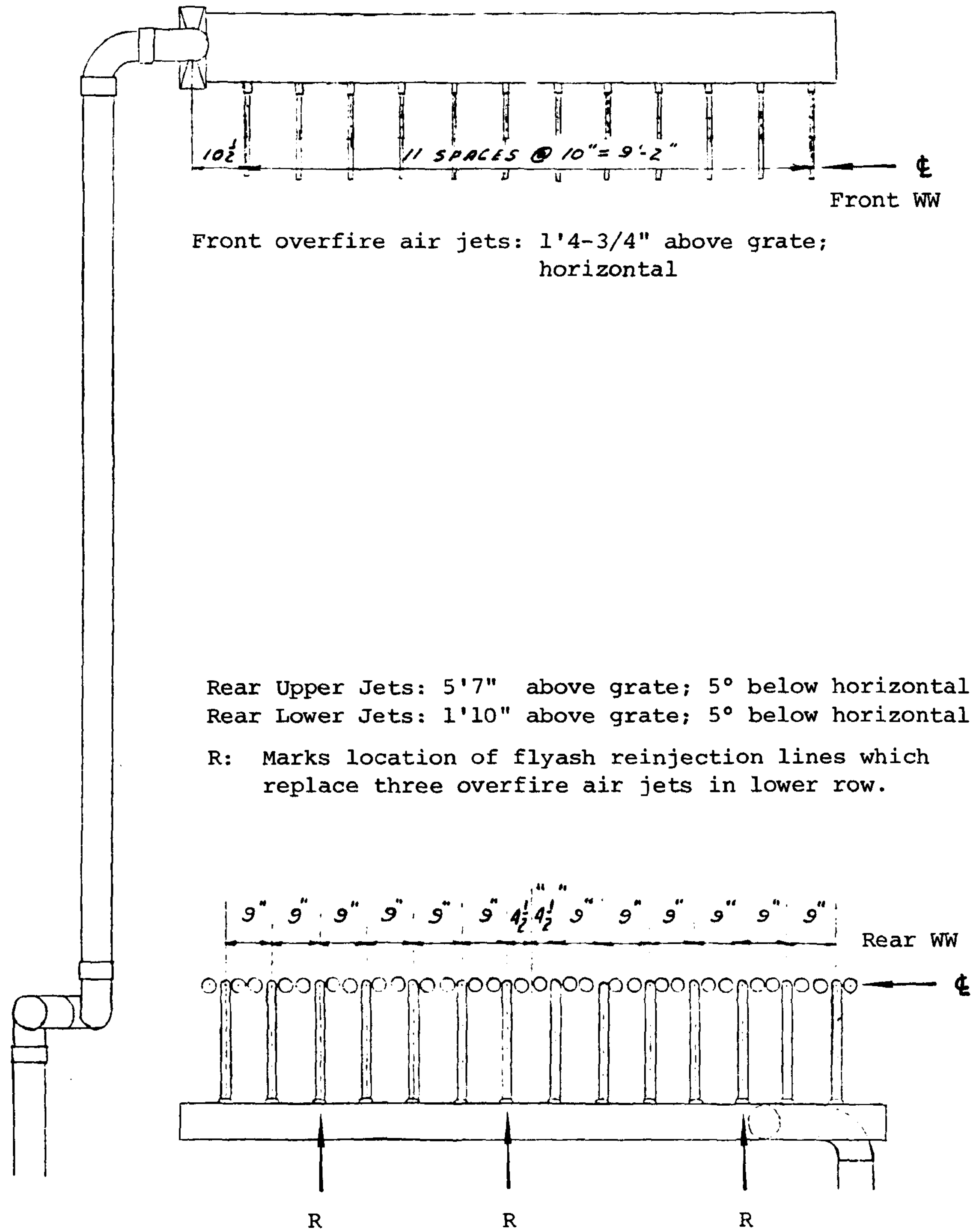


FIGURE 3-2. Plan View of Front and Rear Upper Overfire Air System - Test Site G

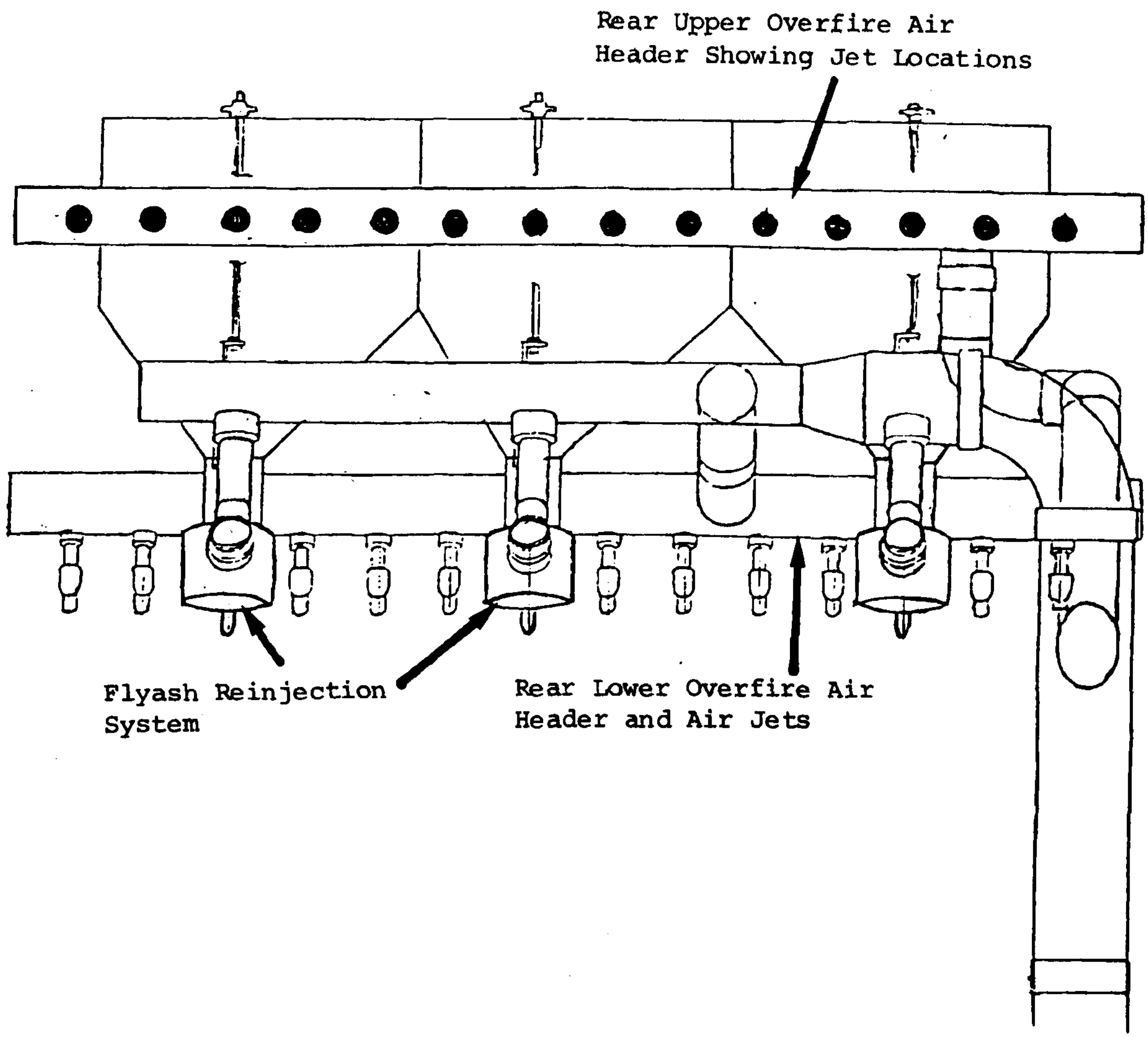


FIGURE 3-3. Rear Elevation Drawing Showing Arrangement of Rear Upper and Lower Overfire Air System, and Flyash Reinjection System - Test Site G.

3.4 MECHANICAL DUST COLLECTOR

The boiler is equipped with a UOP Model 6UPEW HS#10-150 mechanical dust collector. This collector has 150 tubes of 6-inch diameter.

3.5 TEST PORT LOCATIONS

Emission measurements were made at two locations, at the boiler outlet and dust collector outlet (stack). The locations of these sample sites are shown in Figure 3-1, and their geometry is shown in Figure 3-4.

Whenever particulate loading was measured, it was measured simultaneously at both locations using 24-point traverses. Gaseous measurements of O_2, CO_2, NO and hydrocarbons were obtained by pulling samples individually and compositely from selected ports. SOx measurements, brink and SASS samples for organic and trace element determinations were each obtained from single points at the boiler outlet.

3.6 COALS UTILIZIED

The primary coal fired at Test Site G was a 1-1/4 by 1/4 inch modified stoker coal from the White Ash mine in Paintsville, Kentucky. This coal averaged 8.05% ash and 12869 Btu/lb based on ten samples obtained by the test crew.

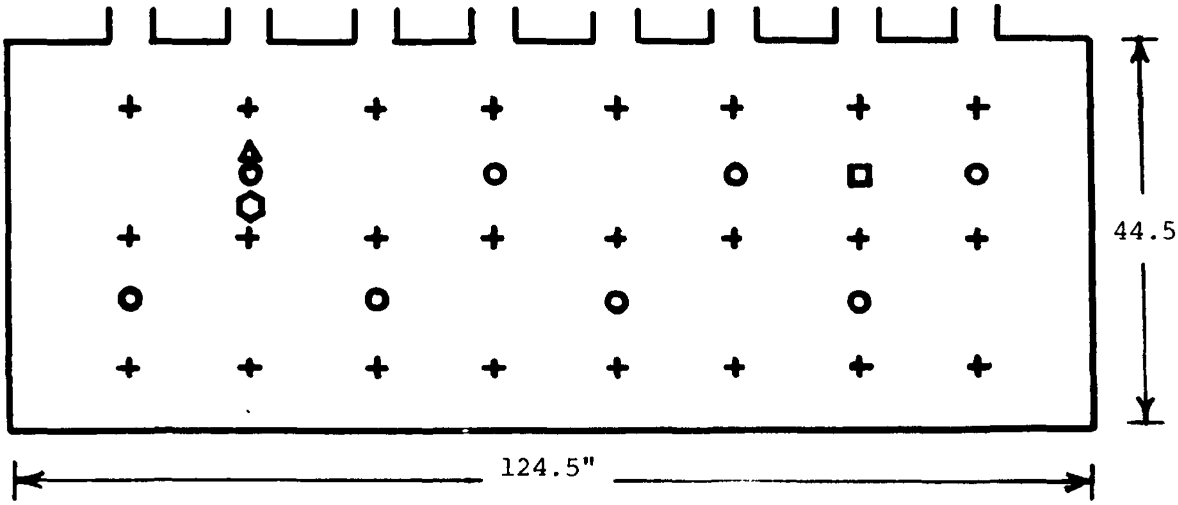
Two lower ash coals were ordered specifically for the test program. These included a 1 by 3/8 inch home stoker coal from the Spurlock Mine in Salisbury, Kentucky, and a 1/2 by 1/8 inch midget stoker coal from the Wheelwright Mine in Price, Kentucky.

When the 4.4% ash Spurlock coal was fired, difficulties were encountered maintaining sufficient ash on the grate to prevent overheating and grate damage. Therefore, testing on this coal was terminated after only two tests.

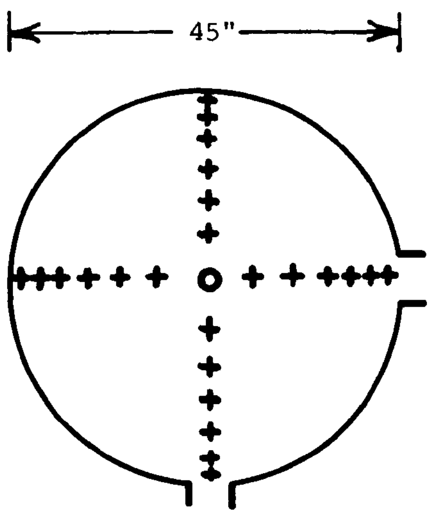
The Wheelwright coal was not fired for fear that its even lower ash content would cause a similar if not worse problem. The contents of a memo relating to this problem is given in Appendix A of this report, and may be referred to for further discussion of the problem.

Because the Wheelwright coal was ruled out, testing on the primary White Ash coal continued until a suitable alternative was found. Three carloads of 1-1/2 by 1/4 inch modified stoker coal from the Pevler mine in Pevler, Kentucky were acquired. This coal contained 7.32% ash and did not cause problems with the grate.

The average "as-fired" analysis for each of the three coals are presented in Table 3-3. The individual coal analysis for each test are included in Section 5.4 of this report. All analyses are based on coal samples obtained by the test crew during each particulate test or SASS test.



CROSS SECTIONAL AREA = 38.47 ft^2
BOILER OUTLET SAMPLING PLANE



CROSS SECTIONAL AREA = 11.04 ft^2
DUST COLLECTOR OUTLET SAMPLING PLANE

✚ PARTICULATE SAMPLING POINT
◘ SASS SAMPLING POINT
● GASEOUS SAMPLING POINT
▲ SO_3 SAMPLING POINT
⬡ BRINK SAMPLING POINT

FIGURE 3-4. Boiler G Sample Plane Geometry

TABLE 3-3

AVERAGE COAL ANALYSIS
TEST SITE G

	White Ash	Spurlock	Pevler
Proximate (as Rec)			
% Moisture	4.56	3.02	4.59
% Ash	8.05	4.42	7.32
% Volatile	35.19	38.98	36.29
% Fired Carbon	52.21	53.59	51.79
Btu/lb	12869	13860	12813
% Sulfur	0.78	1.31	0.76
Ultimate (as Rec)			
% Moisture	4.27	3.32	4.81
% Carbon	72.69	74.59	72.43
% Hydrogen	4.78	5.11	4.90
% Nitrogen	0.98	1.12	1.04
% Chlorine	0.10	0.18	0.05
% Sulfur	0.75	1.31	0.69
% Ash	8.32	6.56	6.95
% Oxygen (diff)	8.07	7.81	9.13

4.0 TEST EQUIPMENT AND PROCEDURES

This section details how specific emissions were measured and the sampling procedures followed to assure that accurate, reliable data were collected.

4.1 GASEOUS EMISSIONS MEASUREMENTS (NOx, CO, CO_2, O_2, HC)

A description is given below of the analytical instrumentation, related equipment, and the gas sampling and conditioning system, all of which are located in a mobile testing van owned and operated by KVB. The systems have been developed as a result of testing since 1970, and are operational and fully checked out.

4.1.1 Analytical Instruments and Related Equipment

The analytical system consists of five instruments and associated equipment for simultaneously measuring the constituents of flue gas. The analyzers, recorders, valves, controls, and manifolds are mounted on a panel in the vehicle. The analyzers are shock mounted to prevent vibration damage. The flue gas constituents which are measured are oxides of nitrogen (NO, NOx), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and gaseous hydrocarbons (HC).

Listed below are the measurement parameters, the analyzer model furnished, and the range and accuracy of each parameter for the system. A detailed discussion of each analyzer follows:

Constituent:	Nitric Oxide/Total Oxides of Nitrogen (NO/NOx)
Analyzer:	Thermo Electron Model 10 Chemiluminescent Analyzer
Range:	0-2.5, 10, 25, 100, 250, 1000, 2500, 10,000 ppm NO
Accuracy:	±1% of full scale

Constituent:	Carbon Monoxide
Analyzer:	Beckman Model 315B NDIR Analyzer
Range:	0-500 and 0-2000 ppm CO
Accuracy:	±1% of full scale

Constituent:	Carbon Dioxide
Analyzer:	Beckman Model 864 NDIR Analyzer
Range:	0-5% and 0-20% CO_2
Accuracy:	±1% of full scale

Constituent:	Oxygen
Analyzer:	Teledyne Model 326A Fuel Cell Analyzer
Range:	0-5, 10, and 25% O_2 full scale
Accuracy:	±1% of full scale

Constituent:	Hydrocarbons
Analyzer:	Beckman Model 402 Flame Ionization Analyzer
Range:	5 ppm full scale to 10% full scale
Accuracy:	±1% of full scale

Oxides of nitrogen. The instrument used to monitor oxides of nitrogen is a Thermo Electron chemiluminescent nitric oxide analyzer. The instrument operates by measuring the chemiluminescent reaction of NO and O_3 to form NO_2. Light is emitted when electronically excited NO_2 molecules revert to their ground state. The resulting chemiluminescence is monitored through an optical filter by a high sensitivity photomultiplier, the output of which is linearly proportional to the NO concentration.

Air for the ozonator is drawn from ambient air through a dryer and a ten micrometer filter element. Flow control for the instrument is accomplished by means of a small bellows pump mounted on the vent of the instrument downstream of a separator that prevents water from collecting in the pump.

The basic analyzer is sensitive only to NO molecules. To measure NOx (i.e., $NO+NO_2$), the NO_2 is first converted to NO. This is accomplished by a converter which is included with the analyzer. The conversion occurs as the gas passes through a thermally insulated, resistance heated, stainless steel coil. With the application of heat, NO_2 molecules in the sample gas are reduced to NO molecules, and the analyzer now reads NOx. NO_2 is obtained by the difference in readings obtained with and without the converter in operation.

Specifications: Accuracy 1% of full scale
Span stability ±1% of full scale in 24 hours
Zero stability ±1 ppm in 24 hours
Power requirements 115±10V, 60 Hz, 1000 watts
Response 90% of full scale in 1 sec. (NOx mode), 0.7 sec. NO mode
Output 4-20 ma

Sensitivity 0.5 ppm
Linearity ±1% of full scale
Vacuum detector operation
Range: 2.5, 10, 25, 100, 250, 1000, 2500, 10,000 ppm full scale

Carbon monoxide. Carbon monoxide concentration is measured by a Beckman 315B non-dispersive infrared analyzer. This instrument measures the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale from 0 to 100 and is then related to the concentration of the specie of interest by calibration curves supplied with the instrument. The operating ranges for the CO analyzer are 0-500 ppm and 0-2000 ppm. (Note: this instrument was out of service during testing at Site G.)

Specifications:
Span stability ±1% of full scale in 24 hours
Zero stability ±1% of full scale in 24 hours
Ambient temperature range 32°F to 120°F
Line voltage 115±15V rms
Response 90% of full scale in 0.5 or 2.5 sec.
Precision ±1% of full scale
Output 4-20 ma

Carbon dioxide. Carbon dioxide concentration is measured by a Beckman Model 864 short path-length, non-dispersive infrared analyzer. This instrument measures the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale from 0 to 100 and is then related to the concentration of the specie of interest by calibration curves supplied with the instrument. The operating ranges for the CO_2 analyzer are 0-5% and 0-20%.

Specifications:
Span stability ±1% of full scale in 24 hours
Zero stability ±1% of full scale in 24 hours
Ambient temperature range 32°F to 120°F
Line voltage 115±15V rms
Response 90% of full scale in 0.5 or 2.5 sec.
Precision ±1% of full scale
Output 4-20 ma

Oxygen. The oxygen content of the flue gas sample is automatically and continuously determined with a Teledyne Model 326A Oxygen analyzer. Oxygen in the flue gas diffuses through a Teflon membrane and is reduced on the surface of the cathode. A corresponding oxidation occurs at the anode internally and an electric current is produced that is proportional to the concentration of oxygen. This current is measured and conditioned by the instrument's electronic circuitry to give a final output in percent O_2 by volume for operating ranges of 0% to 5%, 0% to 10%, or 0% to 25%.

Specifications: Precision ±1% of full scale
Response 90% in less than 40 sec.
Sensitivity 1% of low range
Linearity ±1% of full scale
Ambient temperature range 32-125°F
Fuel cell life expectancy 40,000%-hours
Power requirement 115 VAC, 50-60 Hz, 100 watts
Output 4-20 ma

Hydrocarbons. Hydrocarbons are measured using a Beckman Model 402 hydrocarbon analyzer which utilizes the flame ionization method of detection. The sample is drawn to the analyzer through a heated line to prevent the loss of higher molecular weight hydrocarbons. It is then filtered and supplied to the burner by means of a pump and flow control system. The sensor, which is the burner, has its flame sustained by regulated flows of fuel (40% hydrogen plus 60% helium) and air. In the flame, the hydrocarbon components of the sample undergo a complete ionization that produces electrons and positive ions. Polarized electrodes collect these ions, causing a small current to flow through a circuit. This ionization current is proportional to the concentration of hydrocarbon atoms which enter the burner. The instrument is available with range selection from 5 ppm to 10% full scale as CH_4.

Specifications: Full scale sensitivity, adjustable from 5 ppm CH_4 to 10% CH_4
Ranges: Range multiplier switch has 8 positions: X1, X5, X10, X50, X100, X500, X1000, and X5000. In addition, span control provides continuously variable adjustment within a dynamic range of 10:1
Response time 90% full scale in 0.5 sec.
Precision ±1% of full scale
Electronic stability ±1% of full scale for successive identical samples

Reproducibility ±1% of full scale for successive identical samples
Analysis temperature: ambient
Ambient temperature 32°F to 110°F
Output 4-20 ma
Air requirements 350 to 400 cc/min of clean, hydrocarbon-free air, supplied at 30 to 200 psig
Fuel gas requirements 75 to 80 cc/min of pre-mixed fuel consisting of 40% hydrogen and 60% nitrogen or helium, supplied at 30 to 200 psig
Electrical power requirements 120V, 60 Hz
Automatic flame-out indication and fuel shut-off valve

4.1.2 Recording Instruments

The output of the four analyzers is displayed on front panel meters and are simultaneously recorded on a Texas Instrument Model FLO4W6D four-pen strip chart recorder. The recorder specifications are as follows:

Chart size 9-3/4 inch
Accuracy ±0.25%
Linearity <0.1%
Line voltage 120V±10% at 60 Hz
Span step response: one second

4.1.3 Gas Sampling and Conditioning System

The gas sampling and conditioning system consists of probes, sample lines, valves, pumps, filters and other components necessary to deliver a representative, conditioned sample gas to the analytical instrumentation. The following sections describe the system and its components. The entire gas sampling and conditioning system shown schematically in Figure 4-1 is contained in the emission test vehicle.

4.1.4 Gaseous Emission Sampling Techniques

Boiler access points for gaseous sampling are selected in the same sample plane as are particulate sample points. Each probe consists of one-half inch 316 stainless steel heavy wall tubing. A 100 micrometer Mott Metallurgical Corporation sintered stainless steel filter is attached to each probe for removal of particulate material.

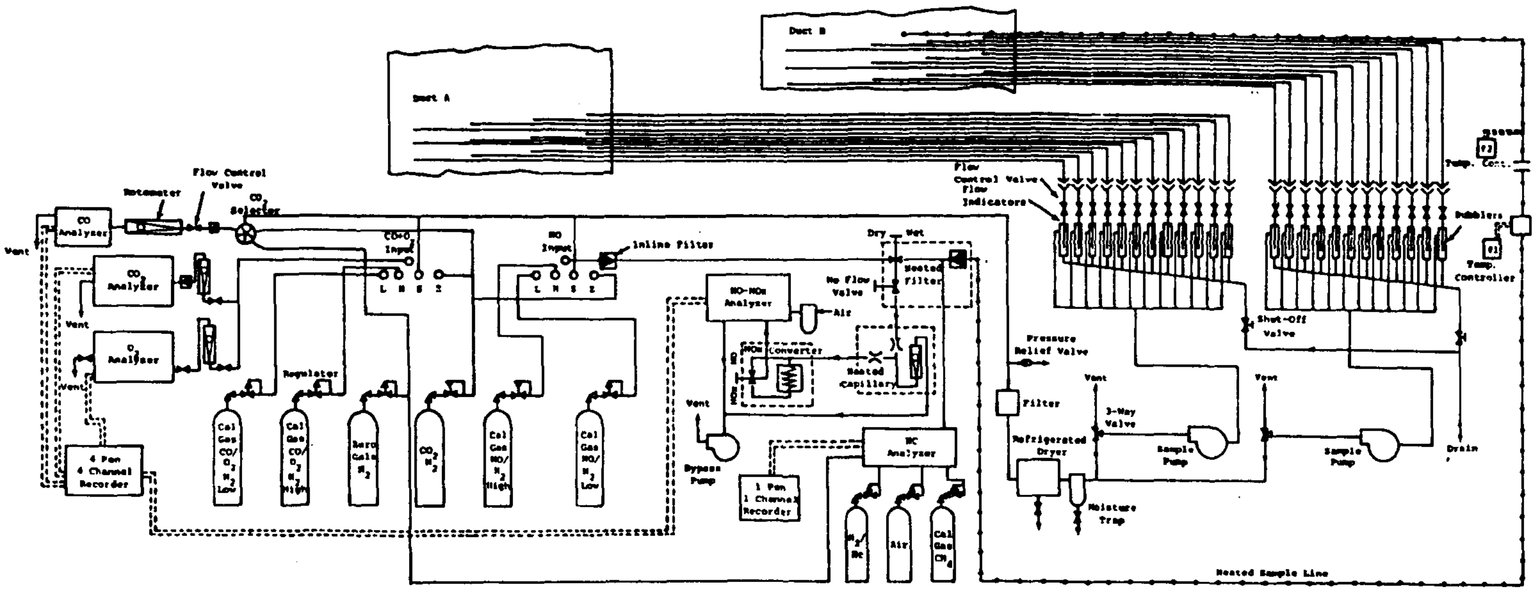


FIGURE 4-1. Flow Schematic of Mobile Flue Gas Monitoring Laboratory

Gas samples to be analyzed for O_2, CO_2, CO and NO are conveyed to the KVB mobile laboratory through 3/8 inch nylon sample lines. After passing through bubblers for flow control, the samples pass through a diaphragm pump and a refrigerated dryer to reduce the sample dew point temperature to 35°F. After the dryer, the sample gas is split between the various continuous gas monitors for analysis. Flow through each continuous monitor is accurately controlled with rotometers. Excess flow is vented to the outside. Gas samples may be drawn both individually and/or compositely from all probes during each test. The average emission values are reported in this report.

4.2 SULFUR OXIDES (SOx) MEASUREMENT AND PROCEDURES

Measurement of SO_2 and SO_3 concentrations is made by wet chemical analysis using both the "Shell-Emeryville" method and EPA Method 6. In the Shell-Emeryville method the gas sample is drawn from the stack through a glass probe (Figure 4-2), containing a quartz wool filter to remove particulate matter, into a system of three sintered glass plate absorbers (Figure 4-3). The first two absorbers contain aqueous isopropyl alcohol and remove the sulfur trioxide; the third contains aqueous hydrogen peroxide solution which absorbs the sulfur dioxide. Some of the sulfur trioxide is removed by the first absorber, while the remainder, which passes through as sulfuric acid mist, is completely removed by the secondary absorber mounted above the first. After the gas sample has passed through the absorbers, the gas train is purged with nitrogen to transfer sulfur dioxide, which has dissolved in the first two absorbers, to the third absorber to complete the separation of the two components. The isopropyl alcohol is used to inhibit the oxidation of sulfur dioxide to sulfur trioxide before it gets to the third absorber.

The isopropyl alcohol absorber solutions are combined and the sulfate resulting from the sulfur trioxide absorption is titrated with standard lead perchlorate solution using Sulfonazo III indicator. In a similar manner, the hydrogen peroxide solution is titrated for the sulfate resulting from the sulfur dioxide absorption.

The gas sample is drawn from the flue by a single probe made of quartz glass inserted into the duct approximately one-third to one-half way.

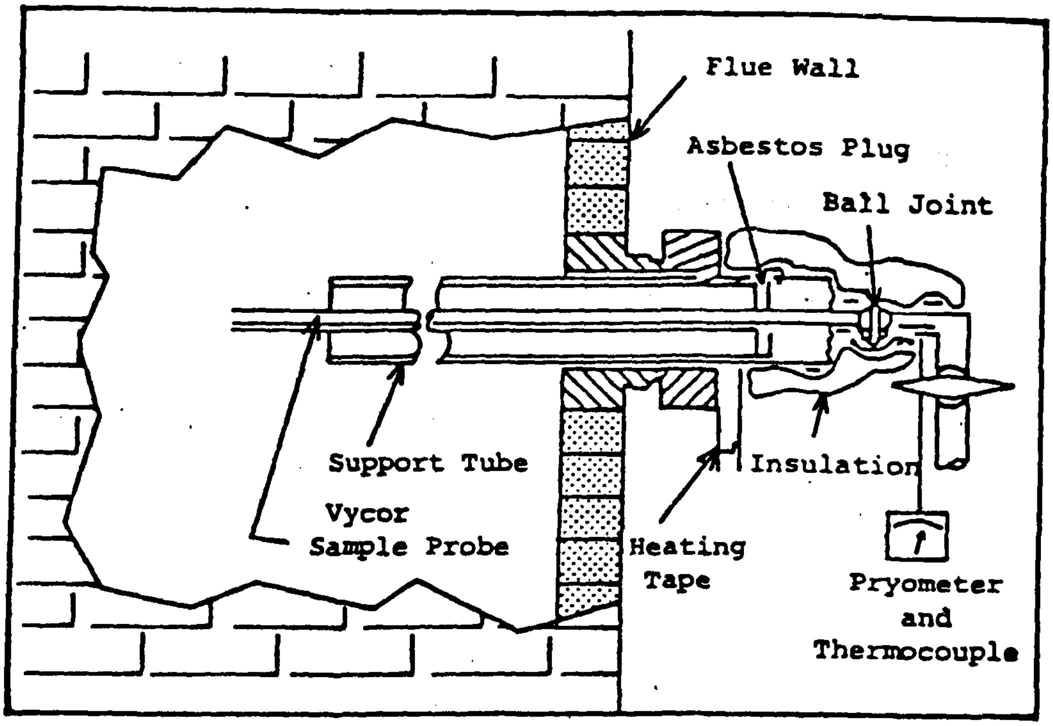


Figure 4-2. SOx Sample Probe Construction

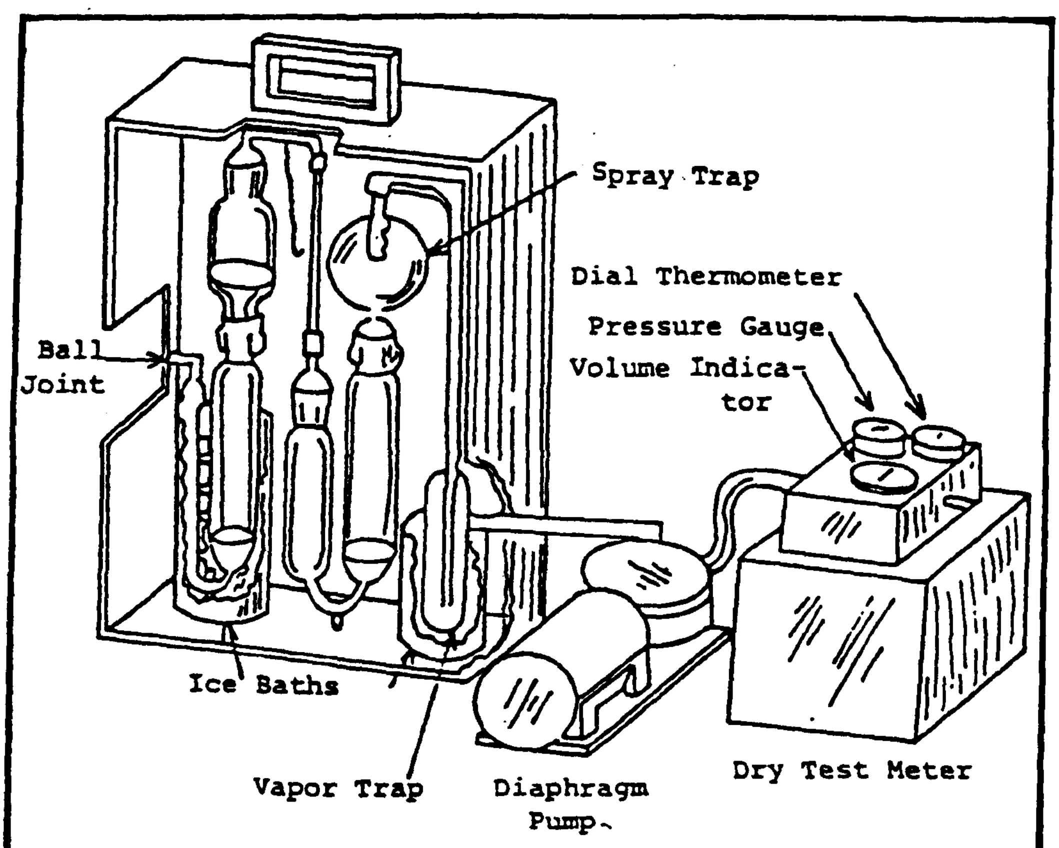


Figure 4-3. Sulfur Oxides Sampling Train
(Shell-Emeryville)

The inlet end of the probe holds a quartz wool filter to remove particulate matter. It is important that the entire probe temperature be kept above the dew point of sulfuric acid during sampling (minimum temperature of 260°C). This is accomplished by wrapping the probe with a heating tape.

EPA Method 6, which is an alternative method for determining SO_2 (Figure 4-4), employs an impinger train consisting of a bubbler and three midget impingers. The bubbler contains isopropanol. The first and second impingers contain aqueous hydrogen peroxide. The third impinger is left dry. The quartz probe and filter used in the Shell-Emeryville method is also used in Method 6.

Method 6 differs from Shell-Emeryville in that Method 6 requires that the sample rate be proportional to stack gas velocity. Method 6 also differs from Shell-Emeryville in that the sample train in Method 6 is purged with ambient air, instead of nitrogen. Sample recovery involves combining the solutions from the first and second impingers. A 10 ml aliquot of this solution is then titrated with standardized barium perchlorate.

Two repetitions of Shell-Emeryville and two reptitions of EPA Method 6 were made during each test.

4.3 PARTICULATE MEASUREMENT AND PROCEDURES

Particulate samples are taken at the same sample ports as the gaseous emission samples using a Joy Manufacturing Company portable effluent sampler (Figure 4-5). This system, which meets the EPA design specifications for Test Method 5, Determination of Particulate Emissions from Stationary Sources (Federal Register, Volume 36, No. 27, page 24888, December 23, 1971), is used to perform both the initial velocity traverse and the particulate sample collection. Dry particulates are collected in a heated case using first a cyclone to separate particles larger than five micrometers and a 100 mm glass fiber filter for retention of particles down to 0.3 micrometers. Condensible particulates are collected in a train of four Greenburg-Smith impingers in an ice water bath. The control unit includes a total gas meter and thermocouple indicator. A pitot tube system is provided for setting sample flows to obtain isokinetic sampling conditions.

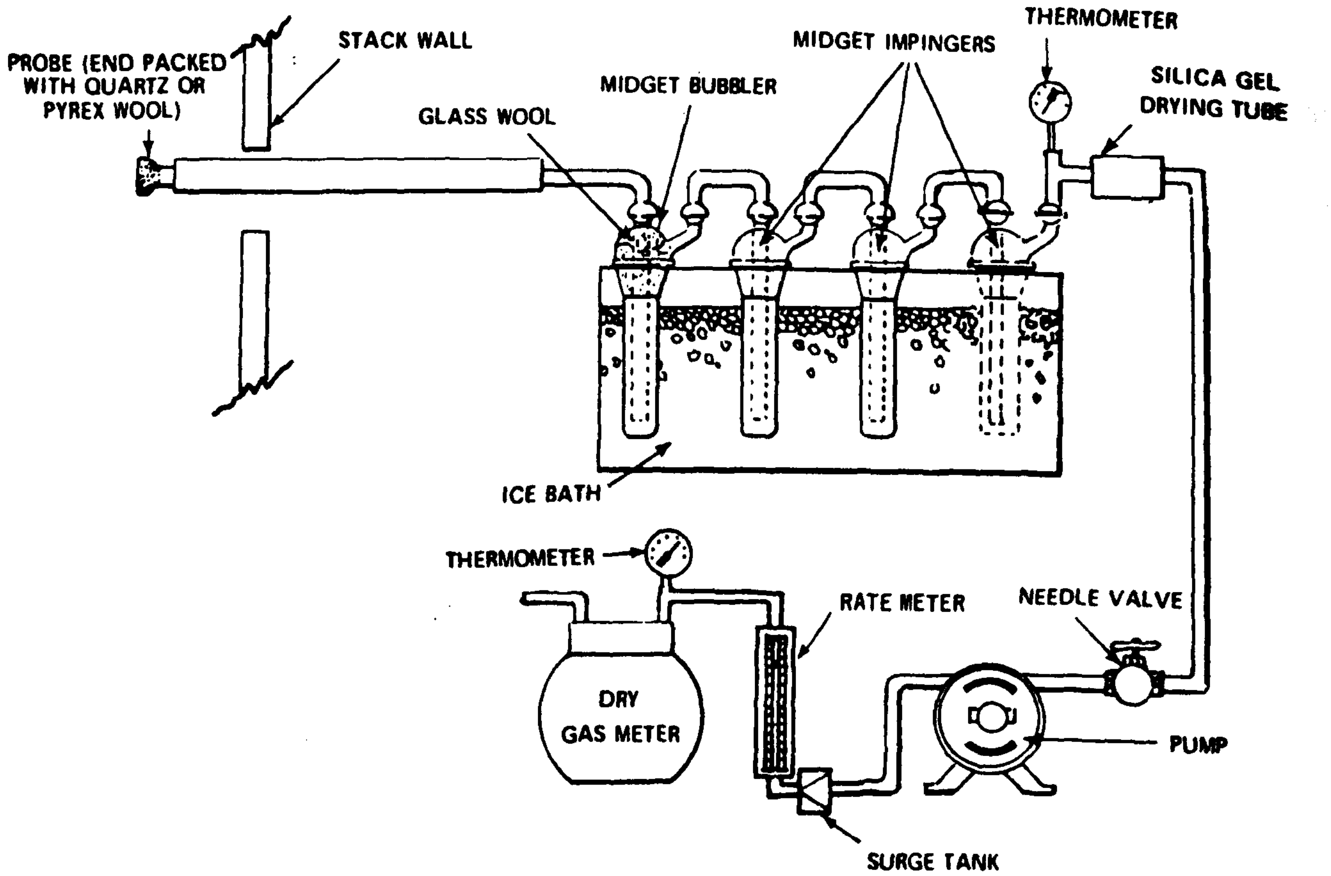


FIGURE 4-4. EPA Method 6 Sulfur Oxide Sampling Train

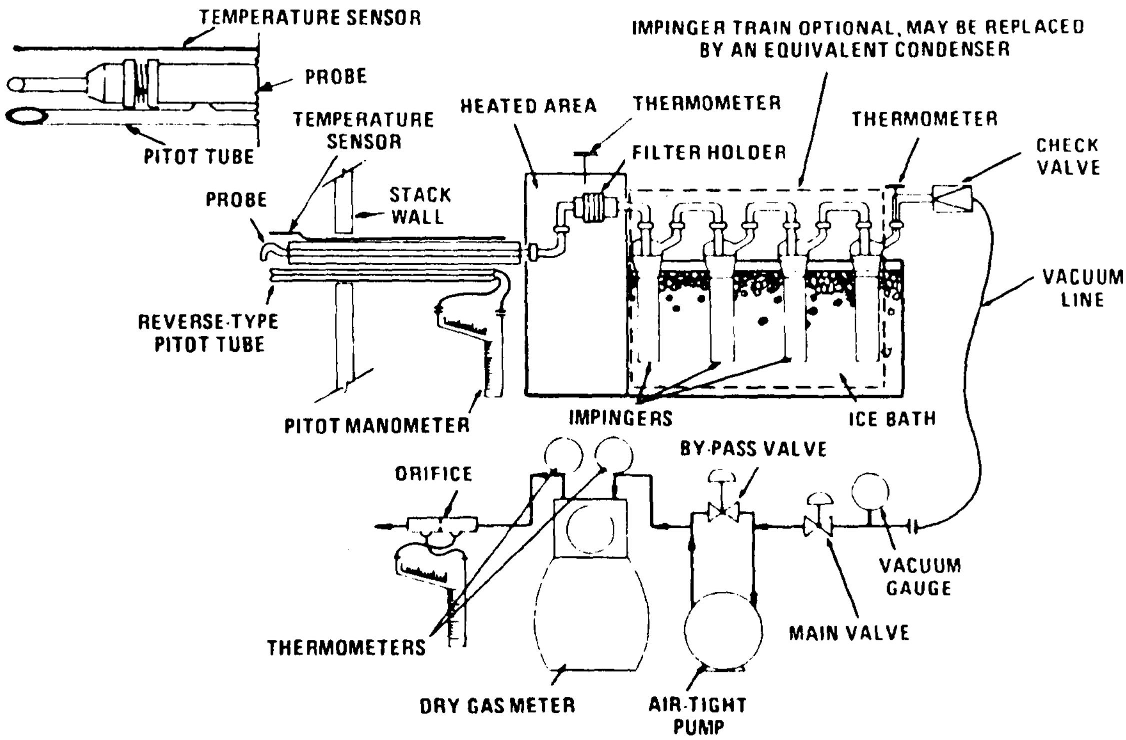


FIGURE 4-5. EPA Method 5 Particulate Sampling Train

All peripheral equipment is carried in the instrument van. This includes a scale (accurate to $\pm$0.1 mg), hot plate, drying oven (212°F), high temperature oven, desiccator, and related glassware. A particulate analysis laboratory is set up in the vicinity of the boiler in a vibration-free area. Here filters are prepared, tare weighed and weighed again after particulate collection. Also, probe washes are evaporated and weighed in the lab.

4.4 PARTICLE SIZE DISTRIBUTION MEASUREMENT AND PROCEDURES

Particle size distribution is measured using several methods. These include the Brink Cascade Impactor, SASS cyclones, and Bahco Classifier. Each of these particle sizing methods has its advantages and disadvantages.

Brink. The Brink cascade impactor is an in-situ particle sizing device which separates the particles into six size classifications. It has the advantage of collecting the entire sample. That is, everything down to the collection efficiency of the final filter is included in the analysis. It has, however, some disadvantages. If the particulate matter is spatially stratified within the duct, the single-point Brink sampler will yield erroneous results. Unfortunately, the particles at the outlets of stoker boilers may be considerably stratified. Another disadvantage is the instrument's small classification range (0.3 to 3.0 micrometers) and its small sample nozzle (1.5 to 2.0 mm maximum diameter). Both are inadequate for the job at hand. The particles being collected at the boiler outlet are often as large as the sample nozzle.

The sampling procedure is straight forward. First, the gas velocity at the sample point is determined using a calibrated S-type pitot tube. For this purpose a hand held particulate probe, inclined manometer, thermocouple and indicator are used. Second, a nozzle size is selected which will maintain isokinetic flow rates within the recommended .02-.07 ft^3/min rate at stack conditions. Having selected a nozzle and determined the required flow rate for isokinetics, the operating pressure drop across the impactor is determined from a calibration curve. This pressure drop is corrected for temperature, pressure and molecular weight of the gas to be sampled.

A sample is drawn at the predetermined ΔP for a time period which is dictated by mass loading and size distribution. To minimize weighing errors, it is desirable to collect several milligrams on each stage. However, to minimize reentrainment, a rule of thumb is that no stage should be loaded above 10 mg. A schematic of the Brink sampling train is shown in Figure 4-6.

Bahco. The Bahco classifier is described in ASME Power Test Code 28. It is an acceptable particle sizing method in the power industry and is often used in specifying mechanical dust collector guarantees. Its main disadvantage is that it is only as accurate as the sample collected. Most Bahco samples are collected by cyclone separation; thus, particles below the cut point of the cyclone are lost. The Bahco samples collected at Test Site G came from the cyclone in the EPA Method 5 particulate train. These samples are spatially representative because they are taken from a 24-point sample matrix. However, much of the sample below about seven micrometers is lost to the filter. The Bahco test data are presented in combination with sieve analysis of the same sample. An attempt was made to correct for the lost portion of the sample.

SASS. The Source Assessment Sampling System (SASS) was not designed principally as a particle sizer but it includes three calibrated cyclones which can be used as such. The SASS train is a single point in-situ sampler. Thus, it is on a par with cascade impactors. Because it is a high volume sampler and samples are drawn through large nozzles (0.25 to 1.0 in.), it has an advantage over the Brink cascade impactor where large particles are involved. The cut points of the three cyclones are 10, 3 and 1 micrometers. A detailed description of the SASS train is presented in Section 4.9.

4.5 COAL SAMPLING AND ANALYSIS PROCEDURE

Coal samples at Test Site G were taken during each test from the units three observation ports immediately above the feeders. The samples were processed and analyzed for both size consistency and chemical composition. Normally coal samples would be taken off the apron of the coal scale feeders, but there were no coal scales at Site G. The observation ports above the feeders were used because they are close enough to the furnace that the coal sampled simultaneously with testing is representative of the coal fired during the testing.

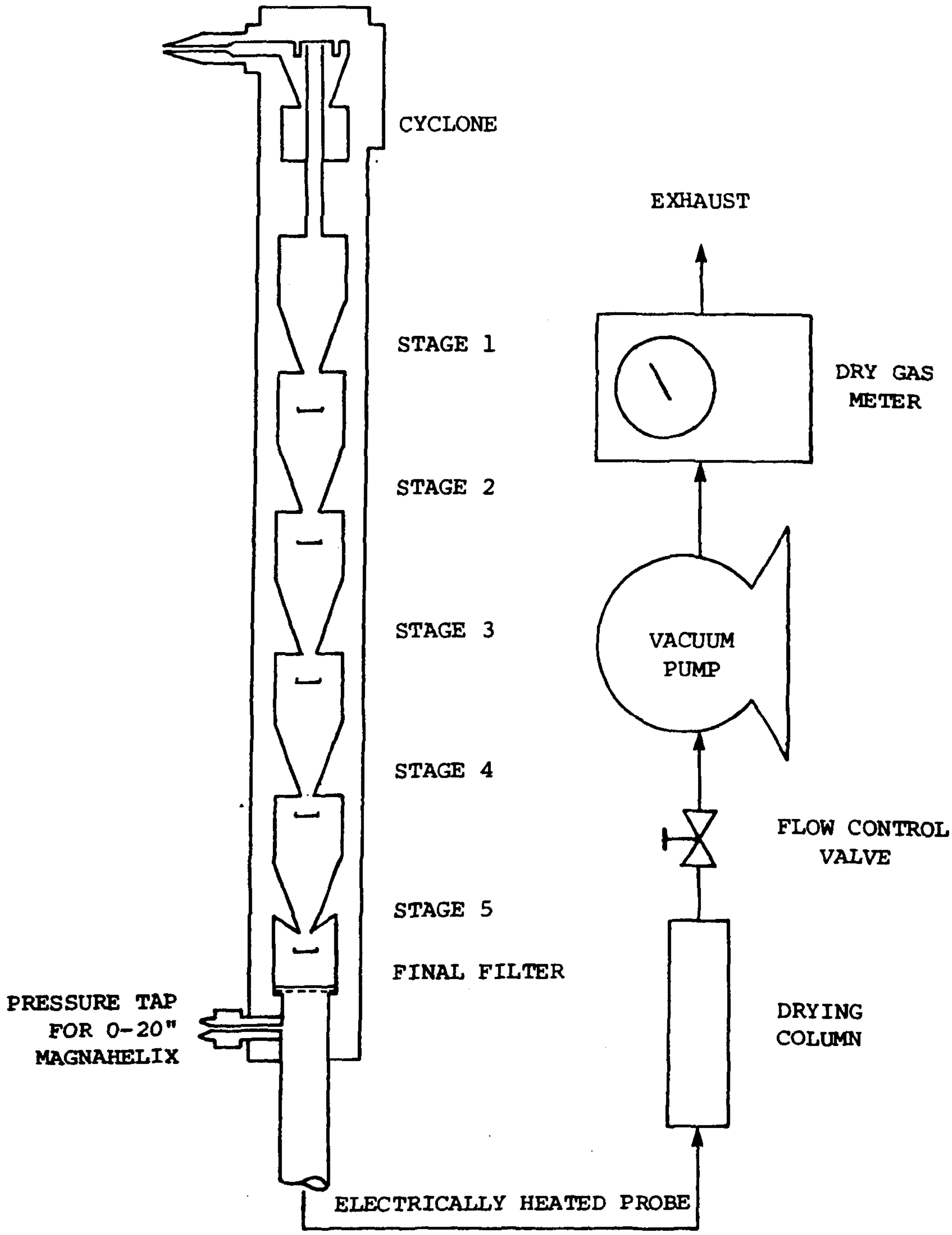


FIGURE 4-6. Brink Cascade Impactor Sampling Train

Representative samples were obtained by first purging the ports of clogged coal and then lifting the ports allowing 10 to 20 pounds of coal to flow into a rectangular bucket. This was done from one of the ports at the start of testing, and once more from each of the other two ports during the test, (three-to-five hours duration), so that a three-increment sample was obtained. The samples were then riffled using a Gilson Model SP-2 Porta Splitter until two representative twenty-pound samples were obtained.

The sample to be used for sieve analysis is weighed, air dried overnight, and re-weighed. Drying of the coal is necessary for good separation of fines. If the coal is wet, fines cling to the larger pieces of coal and to each other. Once dry, the coal is sized using a six tray Gilson Model PS-3 Porta Screen. Screen sizes used are 1", 1/2", 1/4", #8 and #16 mesh. Screen area per tray is 14"x14". The coal in each tray is weighed on a triple beam balance to the nearest 0.1 gram.

The coal sample for chemical analysis is reduced to 2-3 pounds by further riffling and sealed in a plastic bag. All coal samples are sent to Commercial Testing and Engineering Company, South Holland, Illinois. Each sample associated with a particulate loading or particle sizing test is given a proximate analysis. In addition, composite samples consisting of one increment of coal for each test for each coal type receive ultimate analysis, ash fusion temperature, mineral analysis, Hardgrove grindability and free swelling index measurements.

4.6 ASH COLLECTION AND ANALYSIS FOR COMBUSTIBLES

The combustible content of flyash is determined in the field by KVB in accordance with ASTM D3173, "Moisture in the Analysis Sample of Coal and Coke" and ASTM D3174, "Ash in the Analysis Sample of Coal and Coke."

The flyash sample is collected by the EPA Method 5 particulate sample train while sampling for particulates. The cyclone catch is placed in a desiccated and tare-weighed ceramic crucible. The crucible with sample is heated in an oven at 230°F to remove its moisture. It is then desiccated to room temperature and weighed. The crucible with sample is then placed in an electric muffle furnace maintained at a temperature of 1400°F until ignition is complete and the sample has reached a constant weight. It is cooled in a desiccator over desiccant and weighed. Combustible content is calculated as the percent weight loss of the sample based on its post 230°F weight.

At Test Site G the bottom ash samples were collected in several increments from the discharge end of the grate during testing. These samples were mixed, quartered, and sent to Commercial Testing and Engineering Company for combustible determination. Multiclone ash samples were taken from ports near the base of the dust collector hopper. These samples, approximately one quart in size, were sent to Commercial Testing and Engineering Company for combustible determination.

4.7 BOILER EFFICIENCY EVALUATION

Boiler efficiency is calculated using the ASME Test Form for Abbreviated Efficiency Test, Revised, September, 1965. The general approach to efficiency evaluation is based on the assessment of combustion losses. These losses can be grouped into three major categories: stack gas losses, combustible losses, and radiation losses. The first two groups of losses are measured directly. The third is estimated from the ABMA Standard Radiation Loss Chart.

Unlike the ASME test in which combustible losses are lumped into one category, combustible losses are calculated and reported separately for combustibles in the bottom ash, combustibles in the mechanically collected ash which is not reinjected, and combustibles in the flyash leaving the mechanical collector.

4.8 TRACE SPECIES MEASUREMENT

The EPA (IERL-RTP) has developed the Source Assessment Sampling System (SASS) train for the collection of particulate and volatile matter in addition to gaseous samples (Figure 4-7). The "catch" from the SASS train is analyzed for polynuclear aromatic hydrocarbons (PAH) and inorganic trace elements.

In this system, a stainless steel heated probe is connected to an oven module containing three cyclones and a filter. Size fractionation is accomplished in the series cyclone portion of the SASS train, which incorporates the cyclones in series to provide large quantities of particulate matter which are classified by size into three ranges:

A) >10 μm B) 3 μm to 10 μm C) 1 μm to 3 μm

Together with a filter, a fourth cut (<1 μm) is obtained. Volatile organic material is collected in an XAD-2 sorbent trap. The XAD-2 trap is an integral part of the gas treatment system which follows the oven containing the cyclone system. The gas treatment system is composed of four primary components: the gas conditioner, the XAD-2 organic sorbent trap, the aqueous condensate collector, and a temperature controller. The XAD-2 sorbent is a porous polymer resin with the capability of absorbing a broad range of organic species. Some trapping of volatile inorganic species is also anticipated as a result of simple impaction. Volatile inorganic elements are collected in a series of impingers. The pumping capacity is supplied by two 10 cfm high volume vacuum pumps, while required pressure, temperature, power and flow conditions are obtained from a main controller.

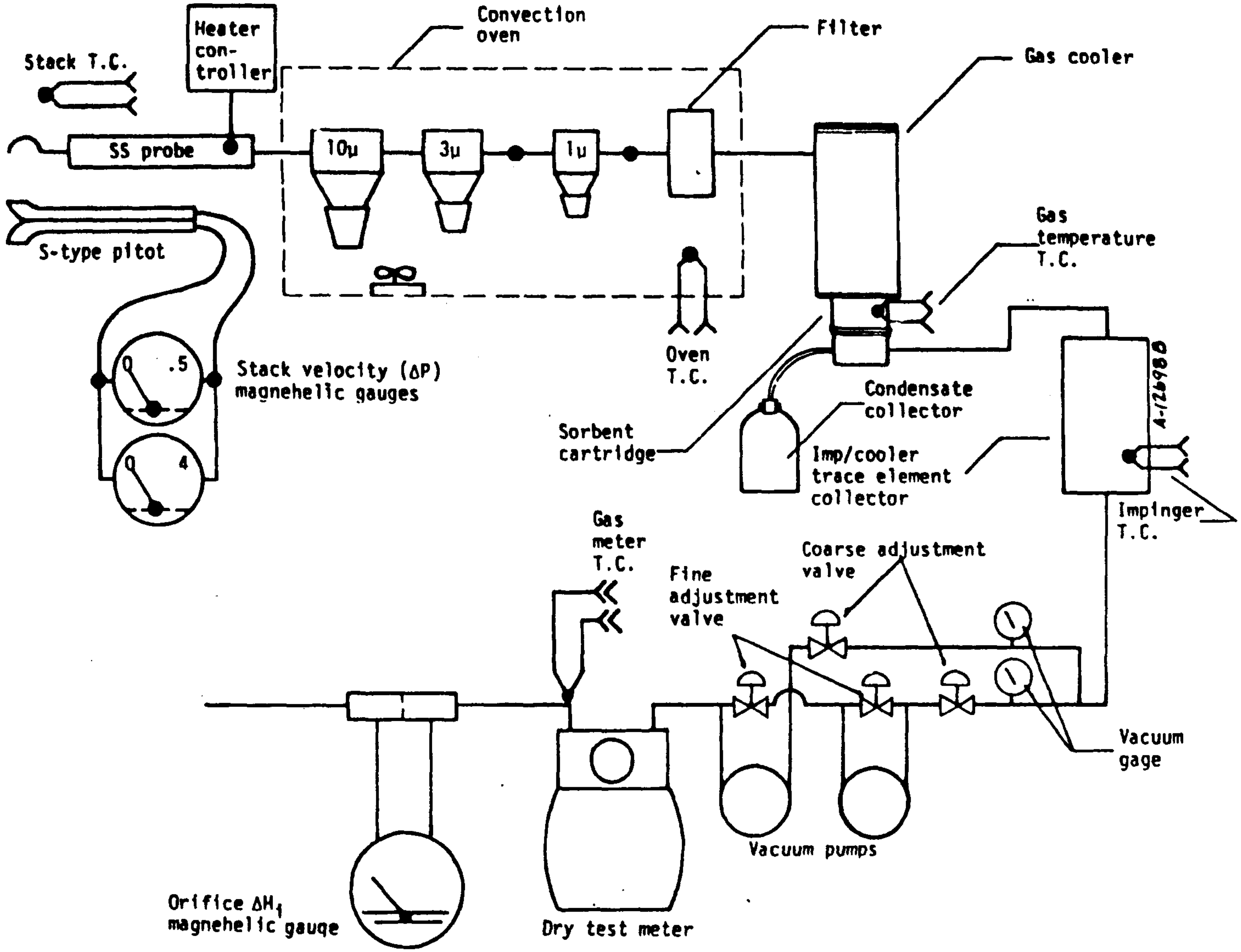


FIGURE 4-7. Source Assessment Sampling System (SASS) Sampling Train

5.0 TEST RESULTS AND OBSERVATIONS

This section of the report presents the results of tests performed on Boiler G. Observations are made regarding the influence on gaseous and particulate emissions and on boiler efficiency as the control parameters were varied. Twenty-six tests were conducted over a six-week test period to develop these data. Reference may be made to the Emission Data Summary, Table 2-2, in the Executive Summary and to Tables 5-28 through 5-31 at the end of this section when reading through the following discussion. Please note that carbon monoxide (CO) data is absent in this report due to the CO analyzer being out of service.

5.1 OVERFIRE AIR

Boiler G had a standard overfire air (OFA) configuration consisting of two rows of jets on the rear water wall and one row of the front water wall above the feeders. The detailed geometry of the overfire air system is described in Section 3.2. Air flow to each row of overfire air jets was controlled by a system of butterfly valves.

Two test sets were run in which overfire air pressure (and thus overfire air flow) was the independent variable. The test results, described in this section, indicate that the overfire air variations examined had little effect on emissions or efficiency. Table 5-1 summarizes the overfire air test data.

Tests were also run to determine the overfire air flow rate as a function of static pressure in the overfire air headers. These tests indicate that overfire air supplies 10% of the combustion air on Boiler G at full load.

5.1.1 Particulate Loading vs Overfire Air

Particulate loading was not affected by a reduction in overfire air pressure. The test data, shown in Table 5-2, show conflicting trends for the two test sets. This is interpreted to be the result of normal variation (or scatter) in the emission level and is unrelated to the overfire air change.

TABLE 5-1

EFFECT OF OVERFIRE AIR ON EMISSIONS AND EFFICIENCY
TEST SITE G

TEST NO.	2	3	23	24
Description	Base line OFA	Low OFA	Base line OFA	Low OFA
OVERFIRE AIR CONDITIONS				
Front Upper, "H_2O	23	18	19	12
Rear Upper, "H_2O	23	13	19	12
Rear Lower, "H_2O	23	12	19	12
FIRING CONDITIONS				
Load, % of Capacity	85	80	76	78
Grate Heat Release, 10^3Btu/hr-ft^2	695	651	618	639
Coal	White Ash	White Ash	Pevler	Pevler
Coal Fines, % Passing 1/4"	40	31	32	32
Excess Air, %	69	67	58	51
BOILER OUTLET EMISSIONS				
Particulate Loading, lbs/10^6Btu	4.27	4.33	4.57	4.00
Combustible Loading, lbs/10^6Btu	2.48	2.26	2.31	2.52
Inorganic Ash Loading, lbs/10^6Btu	1.79	2.07	2.26	1.48
Combustibles in Flyash, %	58.1	52.2	50.6	62.9
O_2, % (dry)	8.9	8.7	8.0	7.3
CO_2, % (dry)	10.2	10.5	11.2	11.7
NO, lbs/10^6Btu	.435	.515	.573	.456
MECHANICAL COLLECTOR OUT EMISSIONS				
Particulate Loading, lbs/10^6Btu	0.22	0.22	0.32	0.26
Combustible Loading, lbs/10^6Btu	--	0.06	0.09	0.08
Inorganic Ash Loading, lbs/10^6Btu	--	0.16	0.23	0.18
Combustibles in Flyash, %	--	29.1	28.8	30.2
Mechanical Collector Efficiency, %	94.8	94.9	93.0	93.5
HEAT LOSSES, %				
Dry Gas	14.74	13.35	12.95	11.94
Moisture in Fuel	0.45	0.41	0.44	0.38
H_2O from Combustion of H_2	4.22	4.00	4.26	4.19
Combustibles in Flyash	3.54	3.22	3.29	3.59
Combustibles in Bottom Ash	1.16	0.27	0.71	0.75
Radiation	0.62	0.66	0.69	0.67
Unmeasured	1.50	1.50	1.50	1.50
Total Losses	26.23	23.41	23.84	23.02
Boiler Efficiency	73.77	76.59	76.16	76.98

TABLE 5-2

PARTICULATE LOADING VS OVERFIRE AIR

Test No.	Overfire Air	Boiler Outlet Particulate Loading $lbs/10^6Btu$	Mechanical Collector Outlet Particulate Loading $lbs/10^6Btu$
2	Baseline	4.27	0.22
3	Low	4.33	0.22
23	Baseline	4.57	0.32
24	Low	4.00	0.26

5.1.2 Nitric Oxide vs Overfire Air

The nitric oxide (NO) data from the two test sets indicate that nitric oxide was not significantly affected by a reduction in overfire air pressure. The test data, shown in Table 5-3, shows a 24% increase in NO for the first test set and a 13% decrease in NO for the second test set based on corrected NO concentrations. These deviations are interpreted as normal data scatter and unrelated to the overfire air pressure change.

The nitric oxide correction to 8% O_2 shown in Table 5-3 is based on the average NO vs O_2 relationship plotted in Figure 5- 11. This plot shows that NO increases 0.046 $lbs/10^6Btu$ for each one percent increase in O_2. This correction removes the effects of the variable oxygen from the test results.

TABLE 5-3

NITRIC OXIDE VS OVERFIRE AIR

Test No.	Overfire Air	% O_2	Measured Nitric Oxide $lbs/10^6Btu$	Nitric Oxide Corrected to 8% O_2 $lbs/10^6Btu$
2	Baseline	8.9	0.435	0.394
3	Low	8.7	0.515	0.483
23	Baseline	8.0	0.573	0.573
24	Low	7.3	0.456	0.488

5.1.3 Boiler Efficiency vs Overfire Air

Boiler efficiency increased when overfire air pressure was reduced in both test sets. However, the efficiency increase appears to be the result of factors other than overfire air. For example, in the first test set a measured 2.82% efficiency increase resulted primarily from a 1.39% decrease in dry gas loss and a 0.89% decrease in bottom ash combustible loss (Table 5-1). Both of these heat loss changes are thought to have resulted from factors other than overfire air. In the second test set a measured 0.82% efficiency gain resulted primarily from a 1.01% decrease in dry gas loss.

The heat loss of primary interest when overfire air is changed is the loss due to combustibles in the flyash. As shown in Table 5-4, this loss did not change significantly in these tests.

TABLE 5-4

BOILER EFFICIENCY VS OVERFIRE AIR

Test No.	Overfire Air	Heat Loss Due to Comb. in Flyash, %	Boiler Efficiency, %
2	Baseline	3.54	73.77
3	Low	3.22	76.59
23	Baseline	3.29	76.16
24	Low	3.59	76.98

5.1.4 Overfire Air Flow Rate

The rate at which air is injected into the furnace above the grate was measured using a standard pitot tube traverse of the overfire air system. The locations at which these measurements were made are shown in the overfire air system schematic, Figure 5-1.

These measurements were made for two reasons. First, by making the measurements at two overfire air settings, it was possible to relate overfire

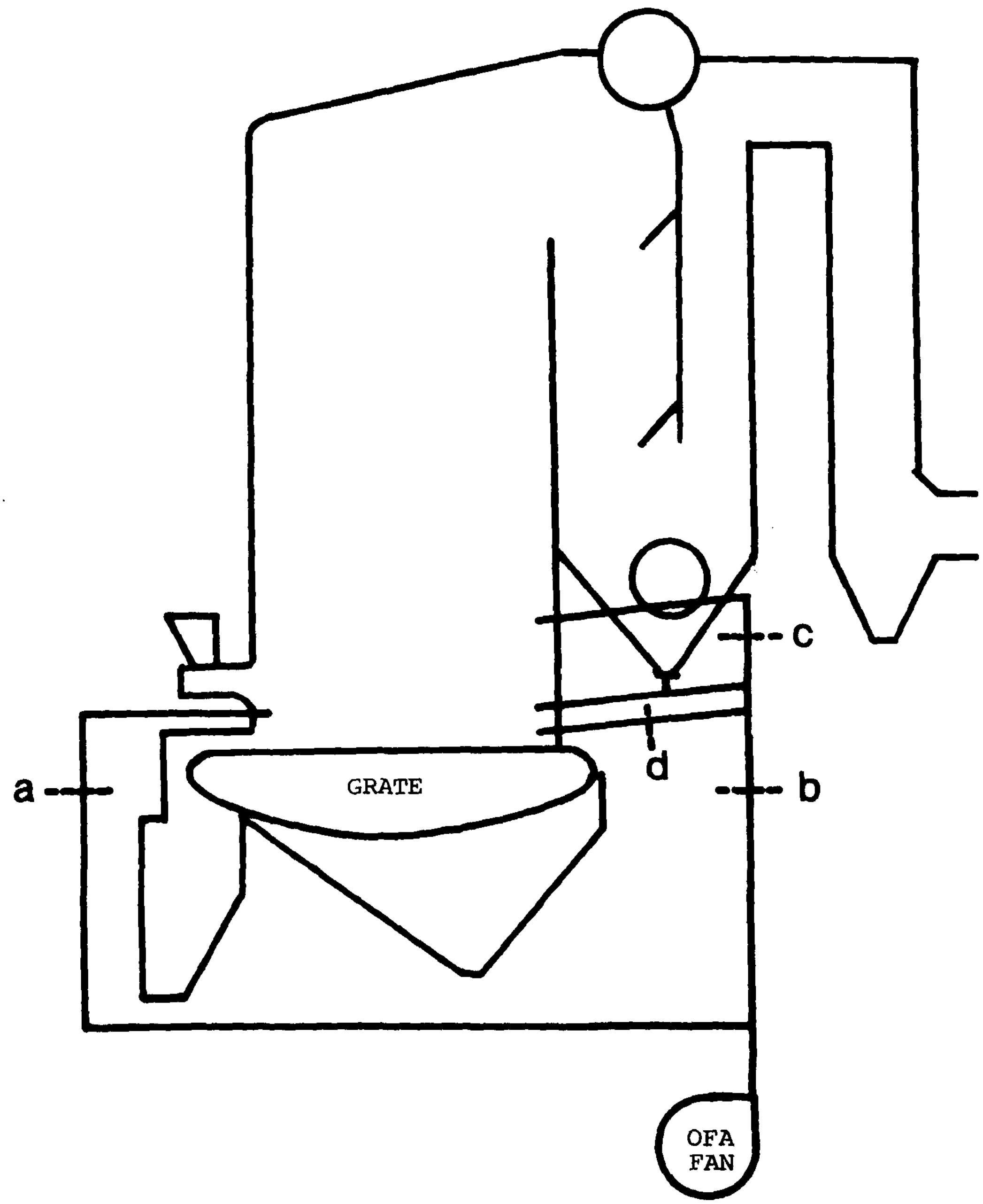


FIGURE 5-1. Schematic of Overfire Air System Showing Location of Flow Rate Measurements - Test Site G

a - Front Lower Overfire Air
b - Rear Main Overfire Air
c - Rear Upper Overfire Air
d - Real Lower Overfire Air

air flow in lbs/hr to the overfire air pressure. Since the overfire air pressure was measured during each test on the boiler, this relationship allows overfire air flow to be accurately estimated for each test. The second reason for making these measurements was to determine the percentage of combustion air introduced above the grate as opposed to that introduced through the grate.

The test results are shown in Table 5-5. It is significant to note that 85% of the overfire air is introduced through the rear water wall on this boiler. The remaining 15% is introduced through the front water wall. Of the air introduced through the rear water wall, 41% went to the upper rear overfire air jets, 31% went to the lower rear overfire air jets and 28% was used in the pneumatic flyash reinjection lines.

In general, the overfire air test data was good considering the difficulties in measuring turbulent gas flows. Maximum OFA Tests 14 and 15 were taken under nearly identical conditions and gave nearly identical results. Test 21 was taken at reduced overfire air pressures and, with the exception of the rear lower OFA measurement, gave the expected reduction in flow rate.

The relationship between overfire air flow rate and overfire air pressure is given in Figure 5-2. Bernoulli's equation for fluid flow through an orifice predicts that flow rate will be proportional to the square root of the pressure drop. This relationship and the maximum overfire air test data were used to create Figure 5-2. With this set of curves it is possible to estimate overfire air flow through each of the three rows of overfire air jets and the flyash reinjection lines by knowing only the static pressure in the duct.

The overfire air system supplies 8% of the total combustion air at full load and 8% O_2. This conclusion is based on calculations indicating that 176,000 lbs/hr air are used to burn coal at 8% O_2, and full load, whereas, the overfire air system on this unit is normally operated wide open at full load and introduces about 14,130 lbs/hr air to the furnace.

TABLE 5-5

OVERFIRE AIR AND REINJECTION AIR FLOW RATES
TEST SITE G

HIGH OVERFIRE AIR PRESSURE, TEST NO. 13

Main Duct	Pressure "H_2O	Air Flow lb/hr	Split	Branch Duct	Pressure "H_2O	Air Flow lb/hr	Split Rear Only
Front OFA	20	2,084	15%				
Rear OFA	22	12,055	85%	Rear Upper OFA	22	4,963	41%
				Rear Lower OFA	21	3,696	31%
				Reinj (by diff)	--	3,396	28%

HIGH OVERFIRE AIR PRESSURE, TEST NO. 14

Main Duct	Pressure "H_2O	Air Flow lb/hr	Split	Branch Duct	Pressure "H_2O	Air Flow lb/hr	Split Rear Only
Front OFA	21	2,238	16%				
Rear OFA	23	11,878	84%	Rear Upper OFA	23	4,840	41%
				Rear Lower OFA	21	3,752	31%
				Reinj (by diff)	--	3,286	28%

MEDIUM OVERFIRE AIR PRESSURE, TEST NO. 21

Main Duct	Pressure "H_2O	Air Flow lb/hr	Split	Branch Duct	Pressure "H_2O	Air Flow lb/hr	Split Rear Only
Front OFA	13	1,919	15%				
Rear OFA	16	10,678	85%	Rear Upper OFA	15	3,474	33%
				Rear Lower OFA	13	3,758	35%
				Reinj (by diff)	--	3,446	32%

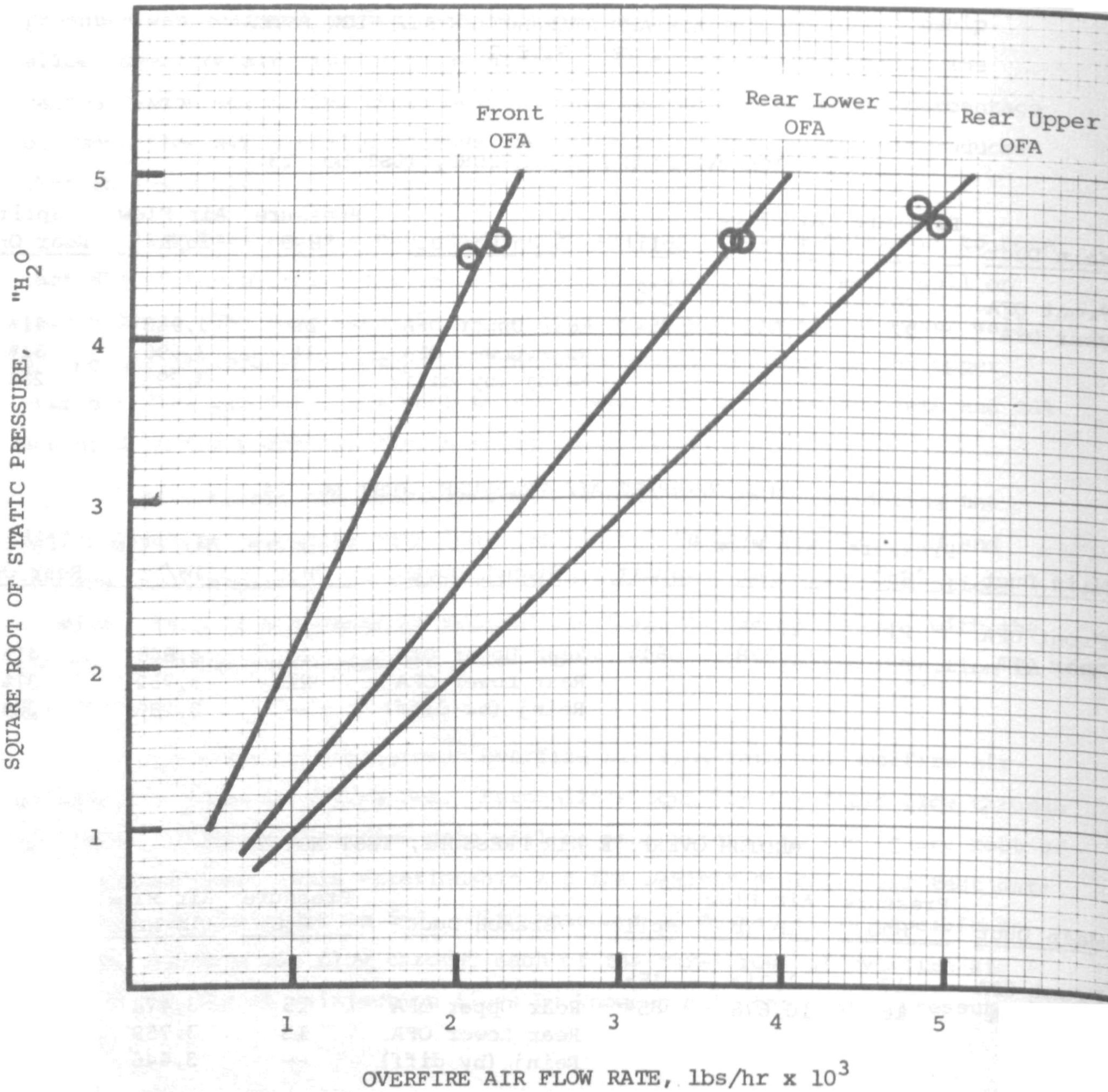


FIGURE 5-2. Overfire Air Flow Rate as a Function of Static Pressure. Relationship is Based on Data From Tests 13 and 14, and on Bernoulli's Equation for Fluid Flow Through an Orifice.

5.2 FLYASH REINJECTION

Boiler G does not reinject flyash from the mechanical dust collector or from the economizer hopper. However, it does reinject flyash pneumatically and continuously from the boiler hopper. During one test, Test 17, the boiler hopper ash was diverted into barrels rather than reinjected. This resulted in a 14% drop in particulate mass loading at the boiler outlet, and a 33% increase in particulate mass loading at the mechanical collector outlet. The data are shown in Table 5-6.

TABLE 5-6

PARTICULATE LOADING VS FLYASH REINJECTION

Test No.	Reinjection from Boiler Hopper	Test Conditions % Load	$\% O_2$	"OFA	Boiler Out Particulate $lbs/10^6Btu$	Mech Coll Out Particulate $lbs/10^6Btu$
5	Yes	102	7.0	22	6.79	0.27
17	No	98	7.4	21	5.86	0.36

The 14% drop in particulate emissions at the boiler outlet is small, but is believed to be a result of the stopped reinjection. Some reduction in particulate emissions was expected. On the other hand, the increased particulate loading at the mechanical collector outlet was not expected and could be due to other factors relating to the collection efficiency of the mechanical dust collector.

The collection rate of the boiler hopper ash was not measured directly but can be deduced from the differences in boiler outlet dust loadings of Tests 5 and 17. By this method, it is estimated that the flyash collection rate is about 0.92 $lbs/10^6Btu$. With a measured combustible fraction of 0.833, this represents a potential efficiency gain of 1.1%.

Table 5-7 lists the combustible heat losses and boiler efficiency for the flyash reinjection test set.

TABLE 5-7

BOILER EFFICIENCY VS FLYASH REINJECTION

Test No.	Reinjection from Boiler Hopper	% Combustibles in Ash: Blr Hpr	D.C. Hpr	Bottom Ash	% Heat Loss: Flyash	Bottom Ash	Boiler Efficiency, %
5	Yes	--	49.9	6.93	4.81	0.52	74.12
17	No	83.3	57.3	7.34	5.45	0.32	73.77

5.3 EXCESS OXYGEN AND GRATE HEAT RELEASE

The boiler at Test Site G was tested for emissions and boiler efficiency at loads ranging from 17% to 102% of the unit's design capacity. At the higher loads, the excess air was varied over a wide range. This section profiles the various emissions and boiler efficiency as a function of these two variables.

Boiler steam loading is expressed in terms of grate heat release. At full load, the measured grate heat release on this unit averaged 809,000 Btu/hr-ft^2 grate area. Excess air is expressed in terms of percent oxygen in the flue gas at the boiler outlet.

It is of special interest to note that some tests were run under swing load conditions while others were run under steady load conditions. These two types of tests are differentiated on many of the plots. The three coals fired are also differentiated on many of the plots.

5.3.1 Excess Oxygen Operating Levels

Figure 5-3 depicts the various conditions of grate heat release and excess oxygen under which tests were run on the boiler at Site G. Different symbols are used to distinguish between the three coals fired.

Full design capacity was easily met on this unit without significant deterioration in combustion efficiency. At full capacity the unit was

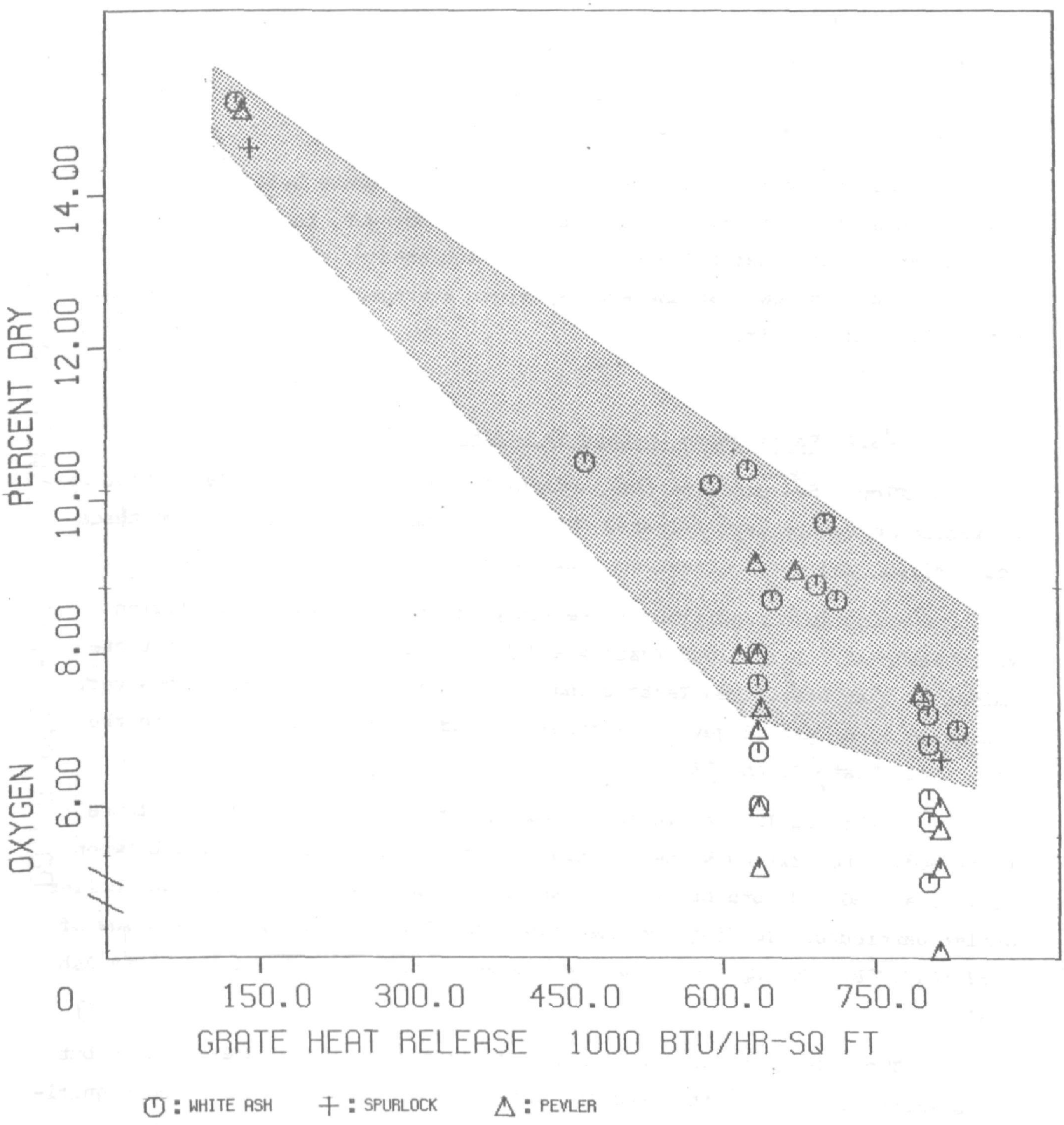


FIG. 5-3
OXYGEN VS. GRATE HEAT RELEASE
TEST SITE G

THIS PLOT SHOWS THE RANGE IN OXYGEN LEVEL UNDER WHICH TESTS WERE CONDUCTED. SHADED AREA ENCOMPASSES ALL OF THE PARTICULATE TESTS. THE LOW O_2 TESTS BELOW THE SHADED AREA WERE SHORT DURATION GASEOUS TESTS.

operated at oxygen levels as low as 7% (48% excess air) without problems for periods of up to four hours. The unit was operated at lower oxygen levels for shorter periods of time including one test (Test 25d) at 4.1% O_2 (22% excess air). The manufacturer's design performance summary sheet for this unit specifies 31% excess air at full load.

Most of the test data was obtained above a grate heat release of 600,000 Btu/hr-ft^2, or 75% of design capacity. However, three tests were also run at a grate heat release of 135,000 Btu/hr-ft^2, or 17% of design capacity. At this low load the excess oxygen averaged 15% which is equivalent to 225% excess air.

5.3.2 Particulate Loading vs Grate Heat Release

Figure 5-4 profiles the particulate loading at the boiler outlet as a function of grate heat release. Different symbols are used for the three coals fired, and special test conditions are identified with labels.

Swing load conditions increased particulate loading when firing white ash coal. Swing load Tests 4 and 10 averaged 60% higher particulate emissions than base fired Tests 2 and 3. When firing Pevler coal, however, the swing load Test 22 gave a particulate loading which was similar to the base fired Tests 23 and 24.

Boiler outlet particulate loading increased as grate heat release increased. When firing White Ash coal, particulate loading tripled between 135,000 and 809,000 Btu/hr-ft^2 (17% and 100% capacity). At full load, boiler outlet particulate loading averaged 5.09 lbs/10^{6}Btu and ranged from a low of 2.93 lbs/10^{6}Btu for Spurlock coal to a high of 6.79 lbs/10^{6}Btu for White Ash coal.

The effects of coal properties are discussed in a later section but it is worth noting here that the low ash Spurlock coal (4.4% ash) had significantly lower full load particulate emissions than either of the other two coals *8.1% and 7.3% ash).

The average ash carryover was 41% for all tests except the three low load tests which averaged 25% ash carryover. The percentage of coal ash carried over as flyash did vary from coal to coal. Table 5-8 shows the basis for this determination.

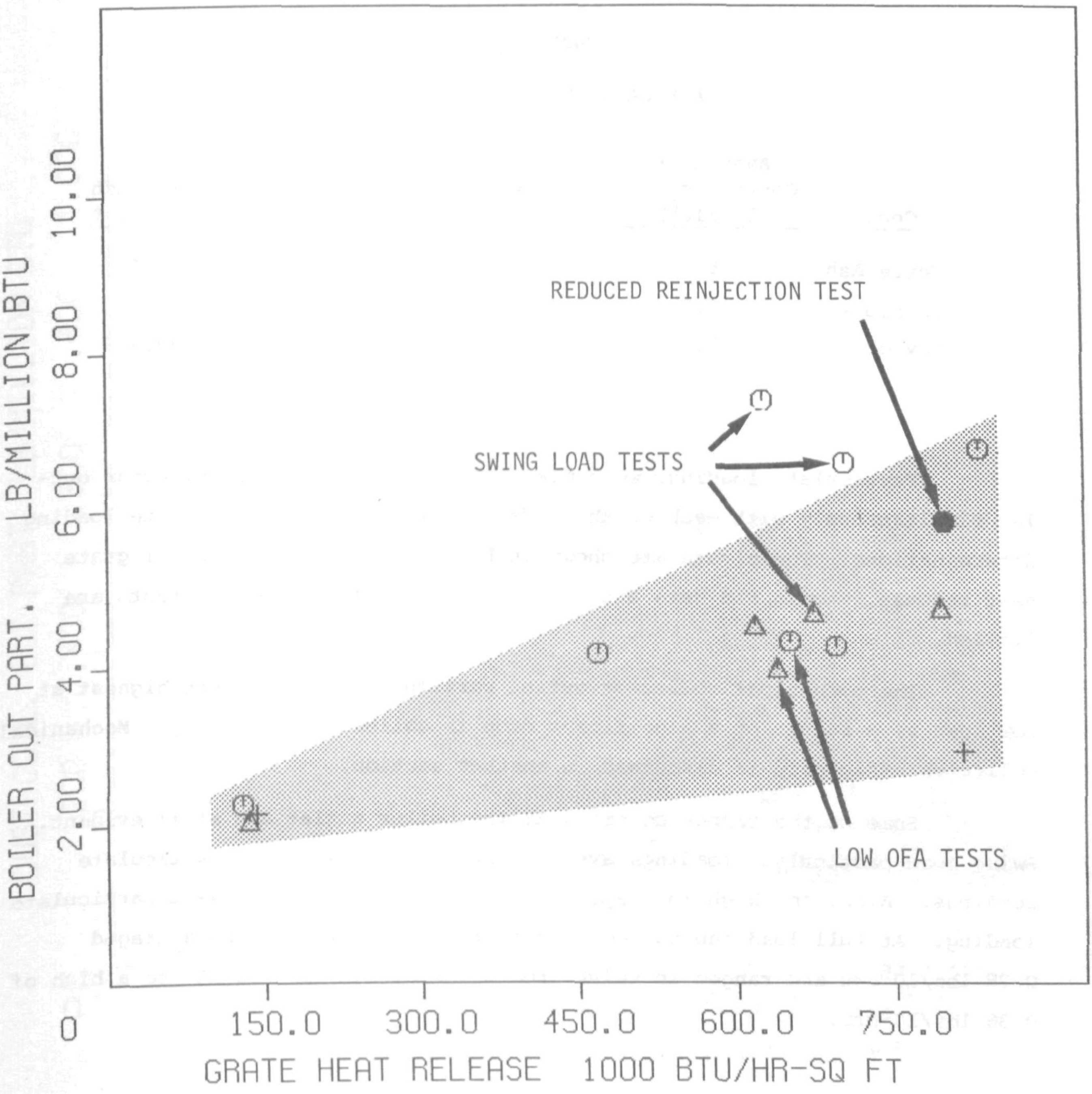


FIG. 5-4
BOILER OUT PART. VS. GRATE HEAT RELEASE
TEST SITE G

TABLE 5-8

ASH CARRYOVER VS COAL TYPE

Coal	Average Ash Content of Coal $lbs/10^6 Btu$	Average Ash Content of Flyash $lbs/10^6 Btu$	Average Ash Carryover, %
White Ash	6.27	2.66	42.4
Spurlock	3.07	1.54	50.2
Pevler	5.97	2.02	33.8

Particulate loadings were measured at the mechanical collector outlet simultaneously with each of the fifteen boiler outlet particulate loading determinations. These data are shown in Figure 5-5 as a function of grate heat release. Again, the data are identified by coal and special tests are labeled.

The mechanical collector outlet particulate loadings are highest at low load as a result of a significant drop in collector efficiency. Mechanical collector efficiency is discussed in another section.

Some of the trends observed at the boiler outlet are still evident. Swing load particulate loadings average higher than base load particulate loadings. Also, the high load Spurlock coal test gives the lowest particulate loading. At full load the collector outlet particulate loading averaged 0.28 $lbs/10^6 Btu$ and ranged in value from a low of 0.17 $lbs/10^6 Btu$ to a high of 0.36 $lbs/10^6 Btu$.

5.3.3 Nitrogen Oxides vs Oxygen and Grate Heat Release

Nitric oxide (NO) and nitrogen dioxide (NO_2) concentrations were measured during each test in units of parts per million (ppm) by volume. A chemiluminescent NOx analyzer was used to make these measurements. The units have been converted from ppm to $lbs/10^6 Btu$ in this report so that they can be more easily compared with existing and proposed emission standards. Table 2-2

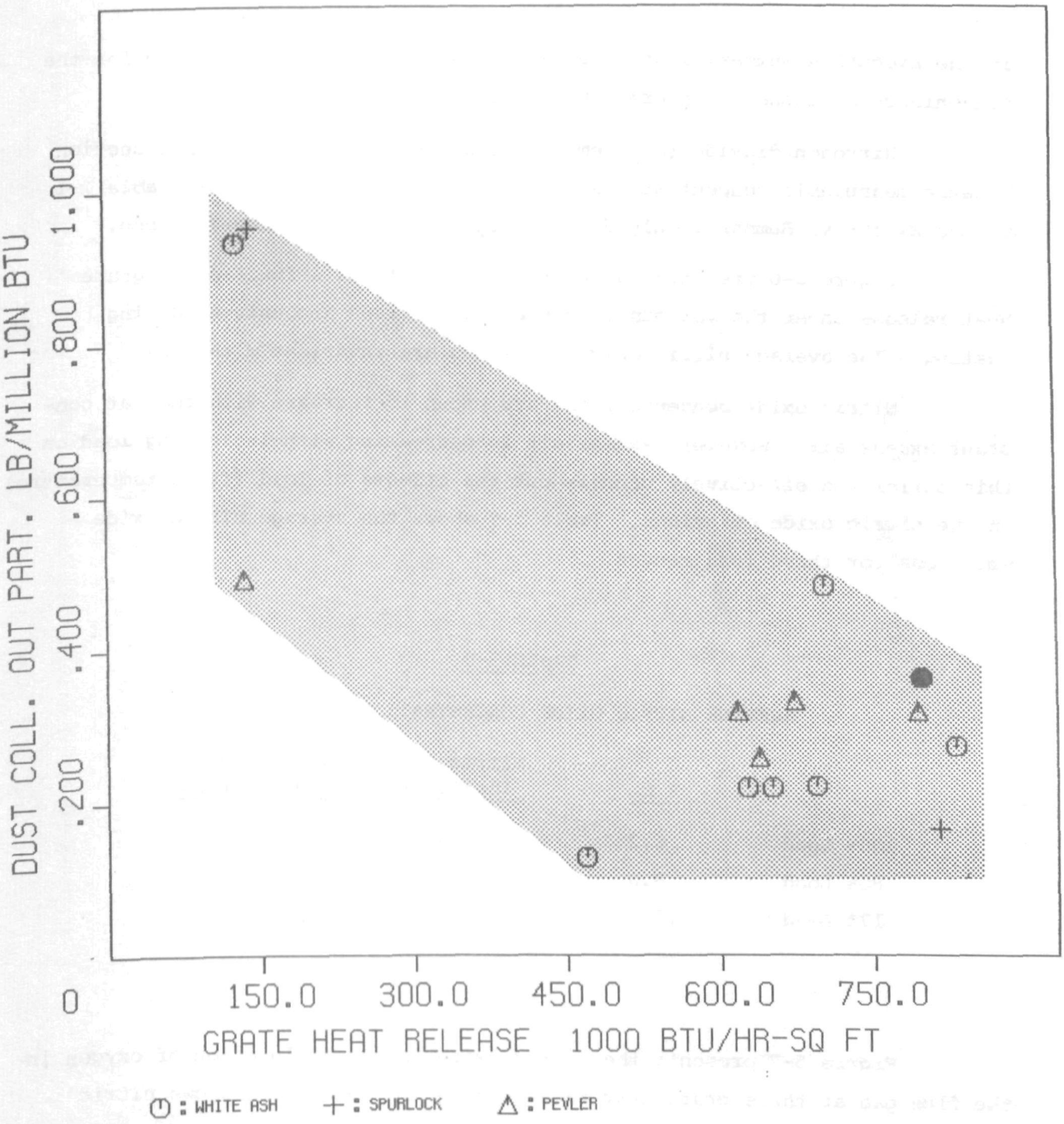


FIG. 5-5
DUST COLL. OUT PART. VS. GRATE HEAT RELEASE
TEST SITE G

in the Executive Summary lists the nitric oxide data in units of ppm for the convenience of those who prefer these units.

Nitrogen dioxide (NO_2) emissions are not discussed in this section because measurable concentrations were not present. As shown in Table 2-1 of the Executive Summary, only 2 of 22 NO_2 readings were above 0.0 ppm.

Figure 5-6 presents the nitric oxide data as a function of grate heat release under the various excess air conditions encountered during testing. The average nitric oxide emissions are invarient with load.

Nitric oxide concentrations are known to increase with load at constant excess air. However, excess air is decreasing with increasing load on this boiler and effectively cancels out the effects of load (flame temperature) on the nitric oxide emissions. Table 5-9 shows the average nitric oxide emissions for three load ranges.

TABLE 5-9

AVERAGE NITRIC OXIDE CONCENTRATIONS VS LOAD

	% O_2	Nitric Oxide lbs/10 Btu	Nitric Oxide ppm @ 3% O_2
100% Load	6.2	0.488	360
80% Load	8.0	0.516	379
17% Load	15.0	0.513	379

Figure 5-7 presents the nitric oxide data as a function of oxygen in the flue gas at three grate heat release ranges. The figure shows nitric oxide concentration increasing with increasing oxygen and with increasing grate heat release.

The nitric oxide data in each grate heat release range (load range) are plotted versus oxygen on an expanded scale in Figures 5-8, 5-9 and 5-10. In each of these plots a trend line was determined by linear regression analysis. The three trend lines are combined in Figure 5-11 to form a nitric

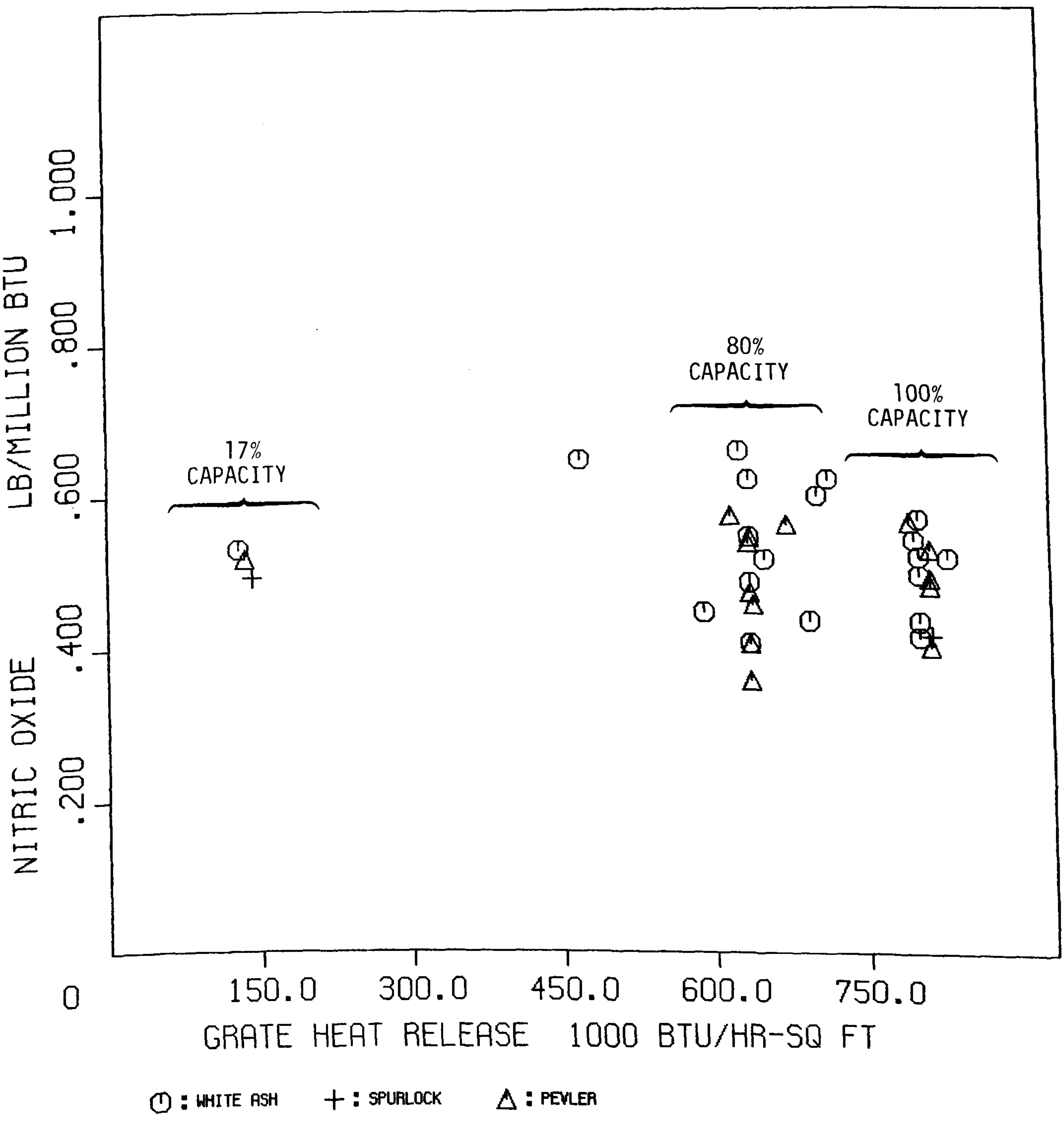


FIG. 5-6
NITRIC OXIDE VS. GRATE HEAT RELEASE
TEST SITE G

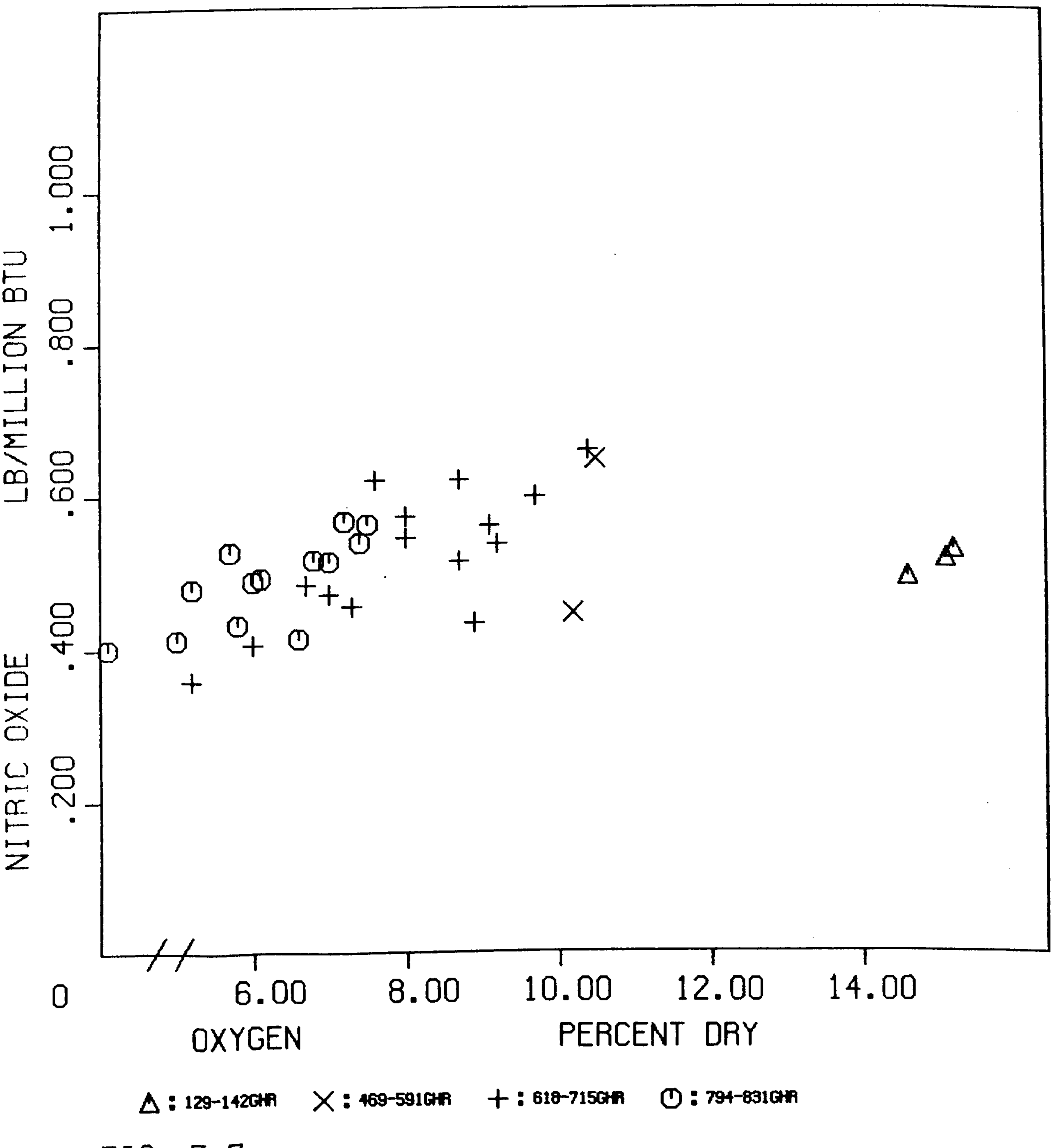


FIG. 5-7
NITRIC OXIDE VS. OXYGEN
TEST SITE G

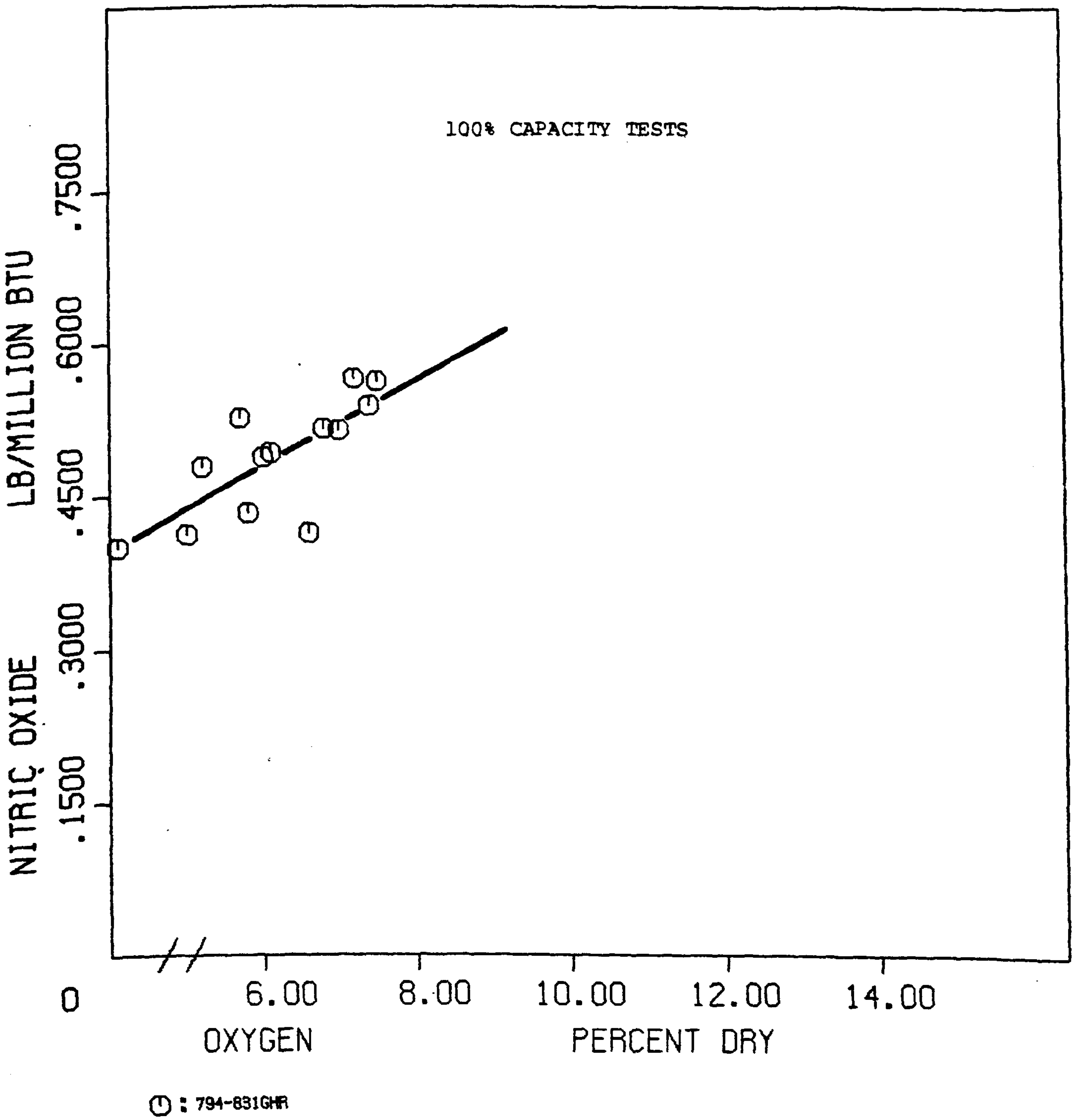


FIG. 5-8

NITRIC OXIDE VS. OXYGEN

TEST SITE G

TREND LINE DETERMINED BY LINEAR REGRESSION ANALYSIS. SLOPE = 0.042, CORRELATION COEFFICIENT r = 0.75

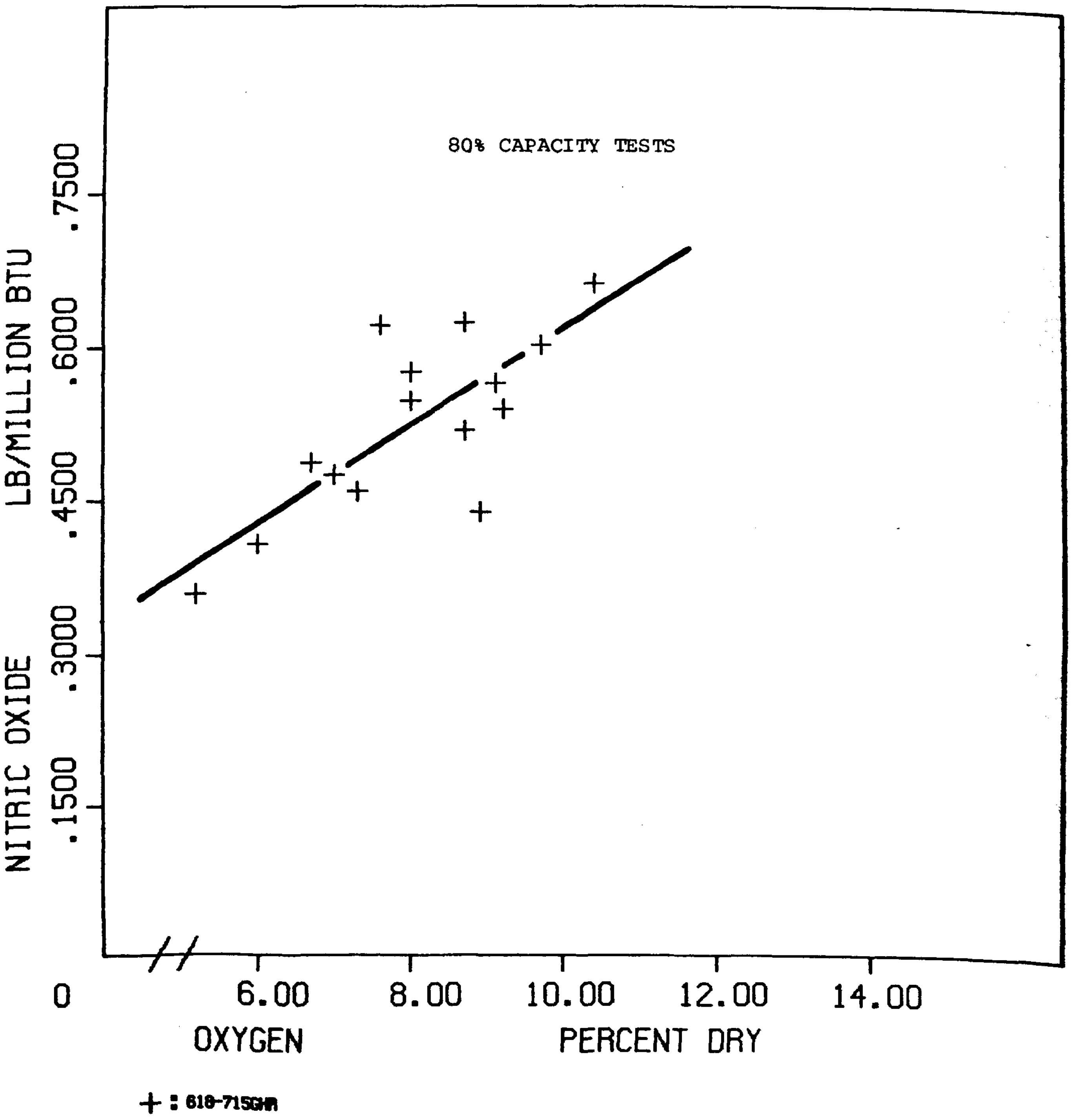


FIG. 5-9

NITRIC OXIDE VS. OXYGEN

TEST SITE G

TREND LINE DETERMINED BY LINEAR REGRESSION ANALYSIS. SLOPE = 0.047, CORRELATION COEFFICIENT r = 0.78

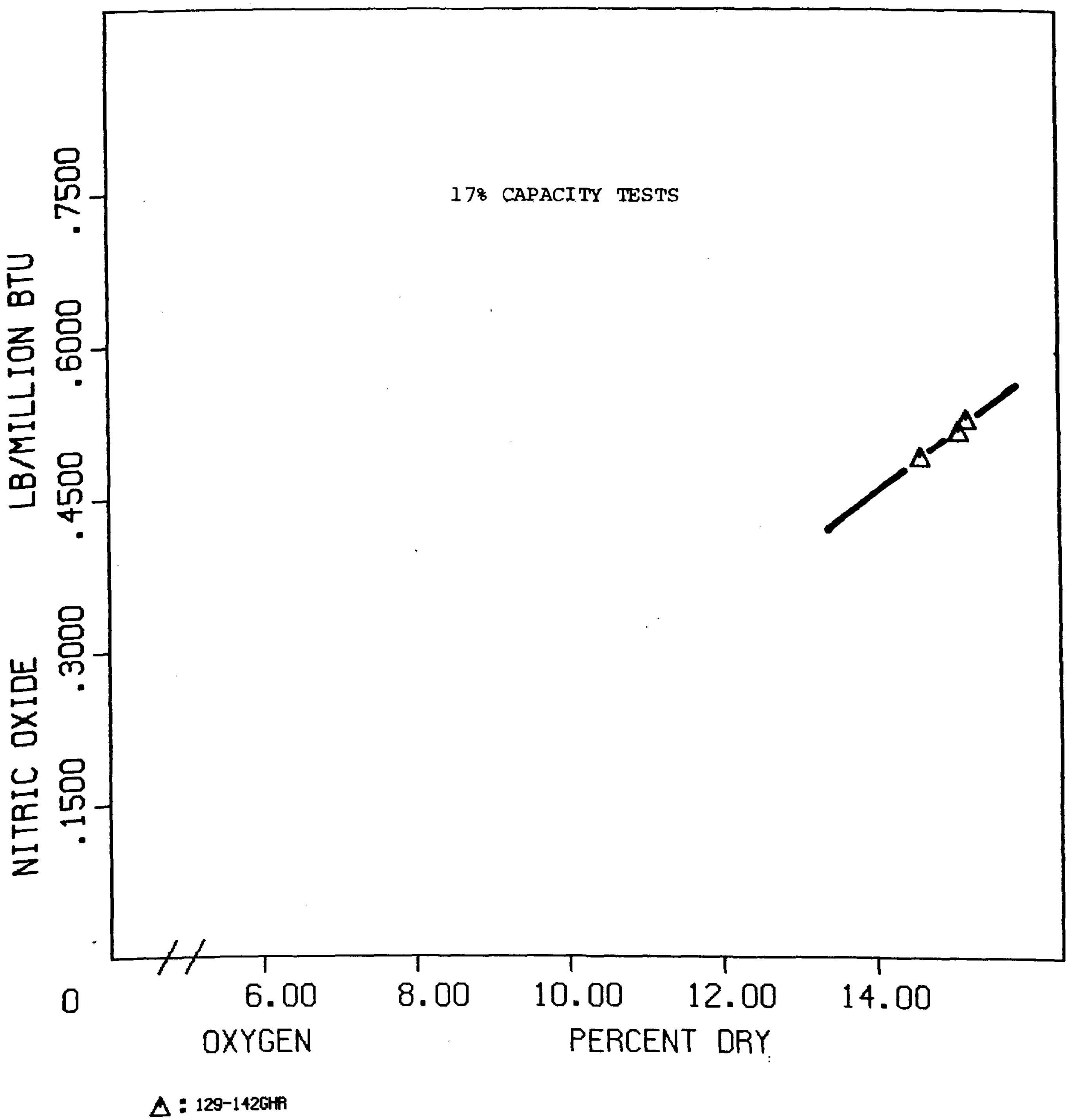


FIG. 5-10
NITRIC OXIDE VS. OXYGEN
TEST SITE G

TREND LINE DETERMINED BY LINEAR REGRESSION ANALYSIS. SLOPE = 0.058, CORRELATION COEFFICIENT r = 0.99

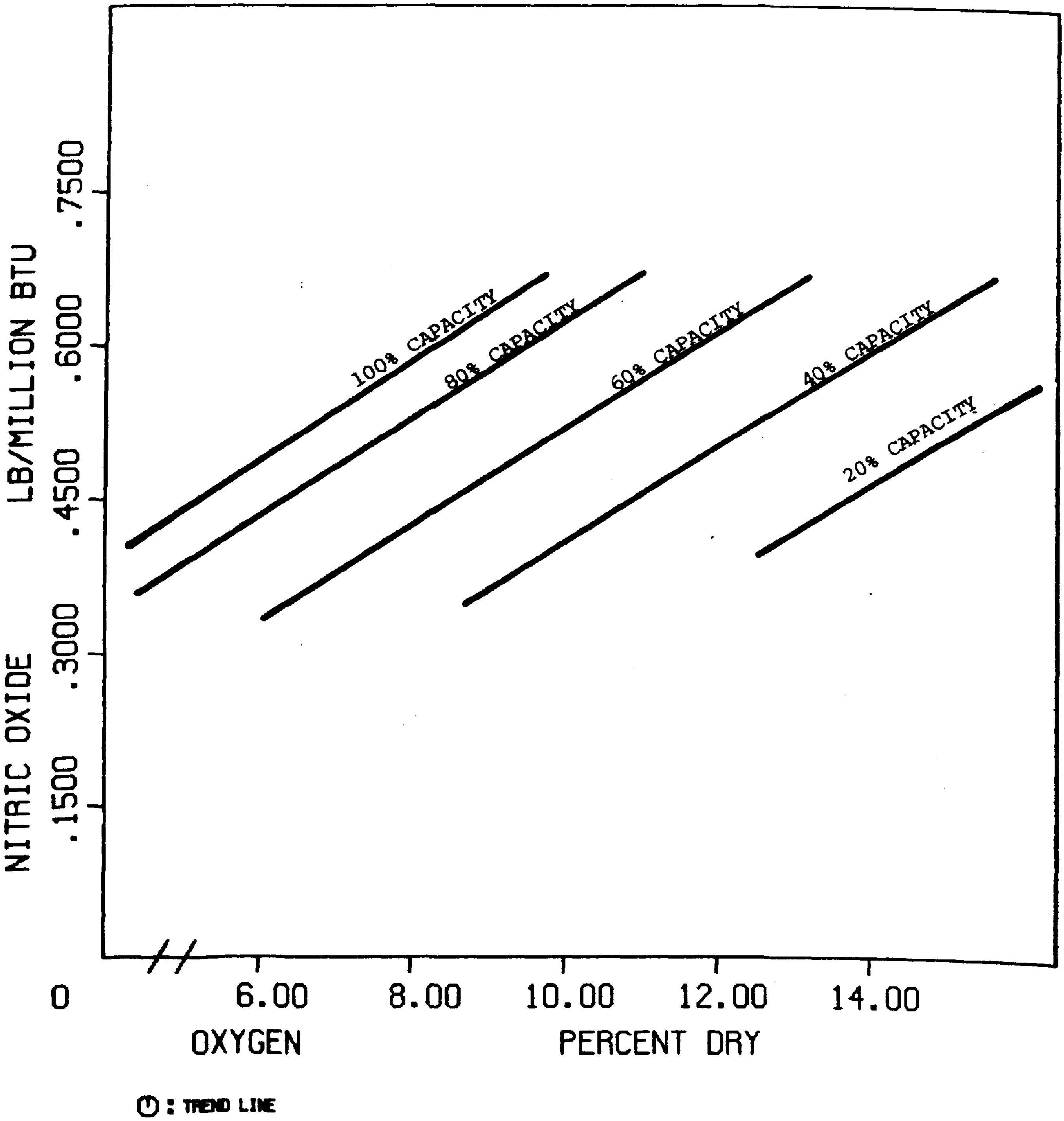


FIG. 5-11
NITRIC OXIDE VS. OXYGEN
TEST SITE G

oxide trend line plot which could be used for predicting nitric oxide concentrations on the unit. The slope of these trend lines indicate that nitric oxide increases by 0.058 $lbs/10^6 Btu$ for each one percent increase in oxygen on this unit.

5.3.4 Hydrocarbons vs Oxygen and Grate Heat Release

Unburned hydrocarbons (HC) were measured during Tests 11 and 12 with a heated sample line and a continuous monitoring instrument utilizing the flame ionization method of detection. The data are plotted as a function of grate heat release in Figure 5-12; and as a function of oxygen in Figure 5-13.

Hydrocarbon concentrations decreased with load, averaging 38 ppm at 100% load and 22 ppm at 80% load. Hydrocarbon concentrations decreased with increasing excess oxygen at 80% load but showed no trend at 100% load.

5.3.5 Combustibles in the Ash vs Oxygen and Grate Heat Release

Flyash samples collected at the boiler outlet, mechanical collector outlet and mechanical collector hopper were baked in a high temperature oven for determination of combustible content. Bottom ash samples were also processed in this manner. The test data for each of these sample locations are plotted as a function of grate heat release in Figures 5-14, 5-15, 5-16 and 5-17.

In general, combustible content of the bottom ash and boiler outlet flyash was higher at high loads than at low loads. All trends with grate heat release (load) are slight.

Combustibles in the ash did not vary as a function of oxygen. This relationship is not shown in any figures in this report, but it was examined and no relationship was found.

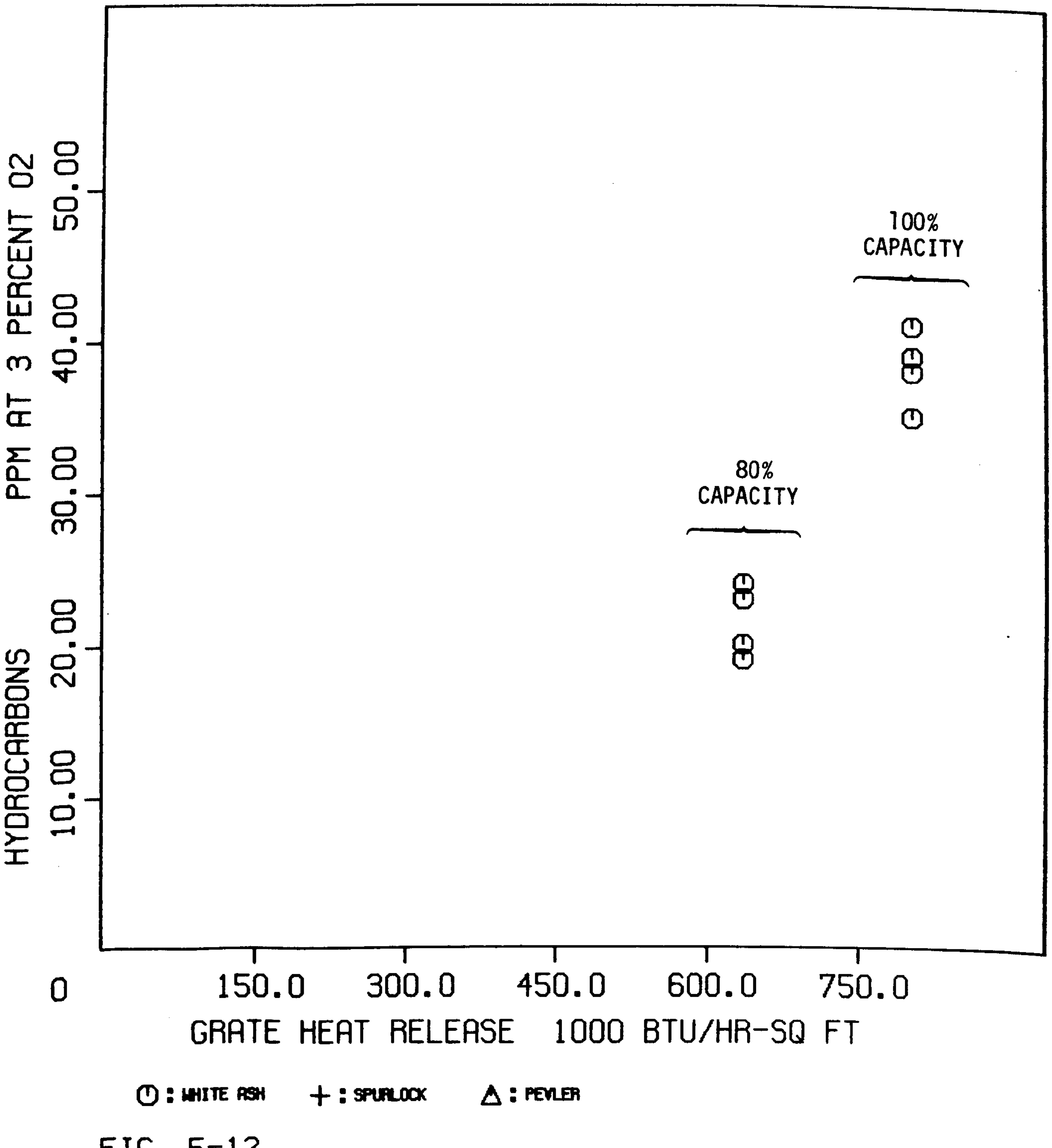


FIG. 5-12
HYDROCARBONS VS. GRATE HEAT RELEASE
TEST SITE G

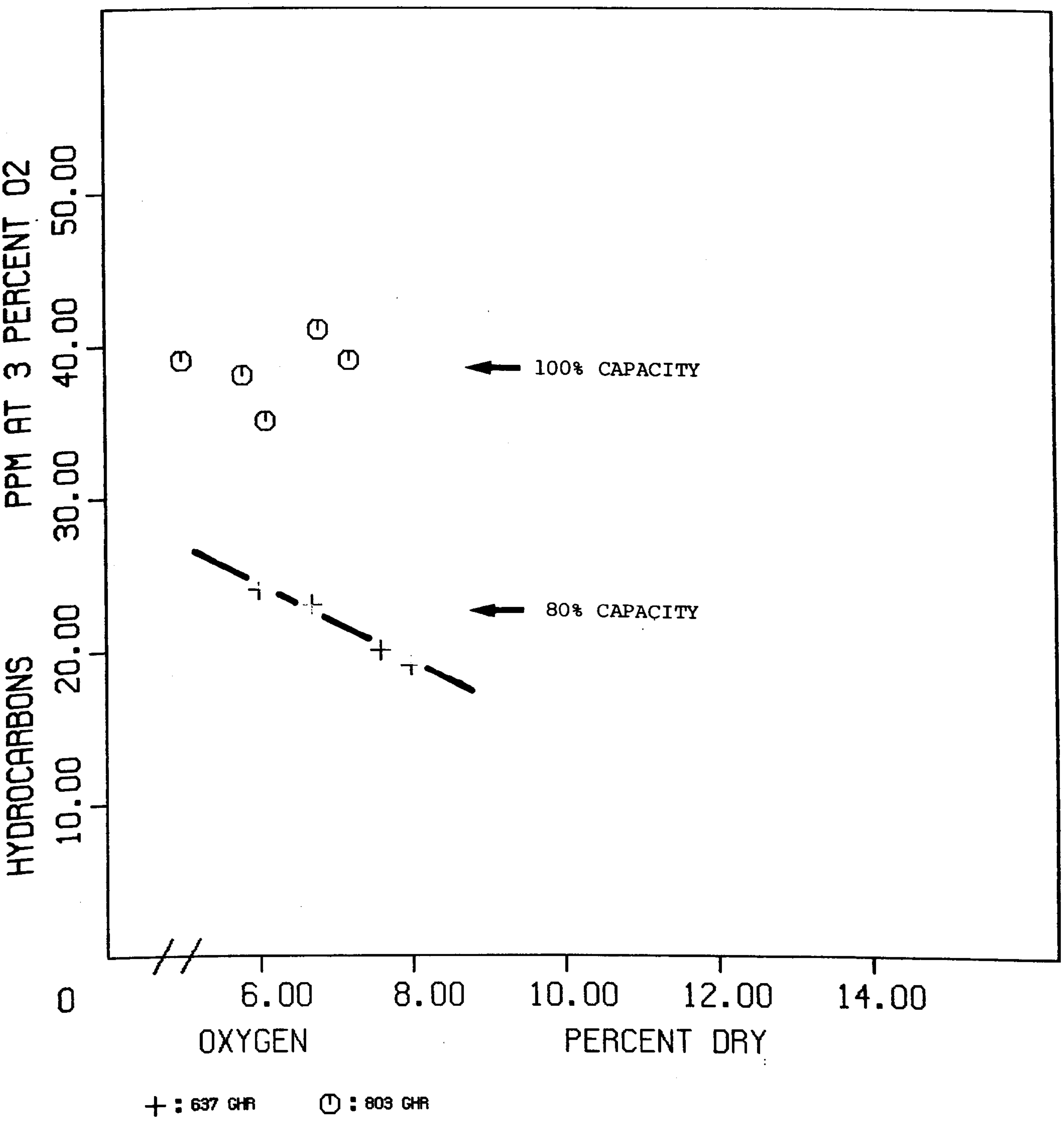


FIG. 5-13
HYDROCARBONS VS. OXYGEN
TEST SITE G

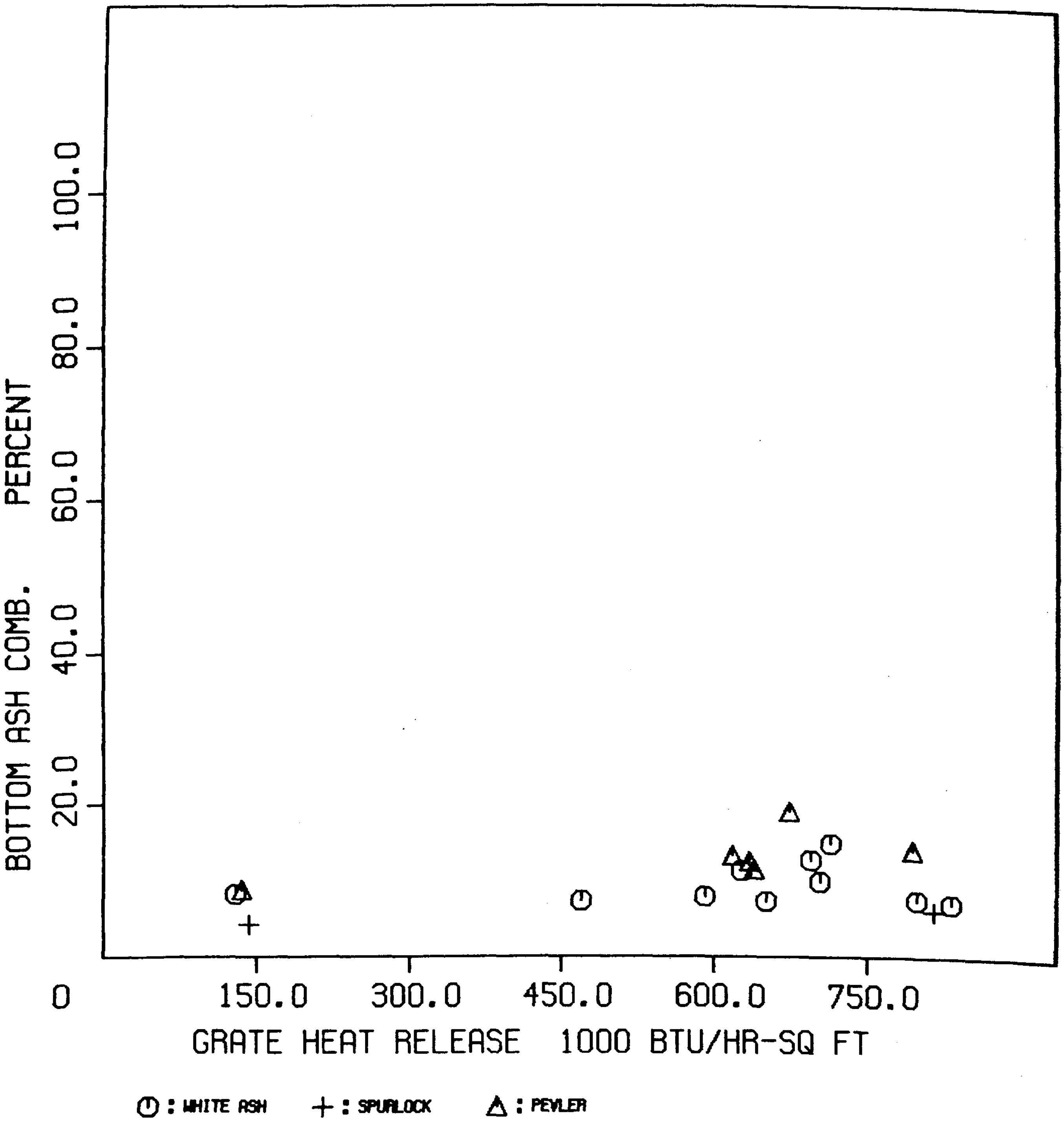


FIG. 5-14
BOTTOM ASH COMB. VS. GRATE HEAT RELEASE
TEST SITE G

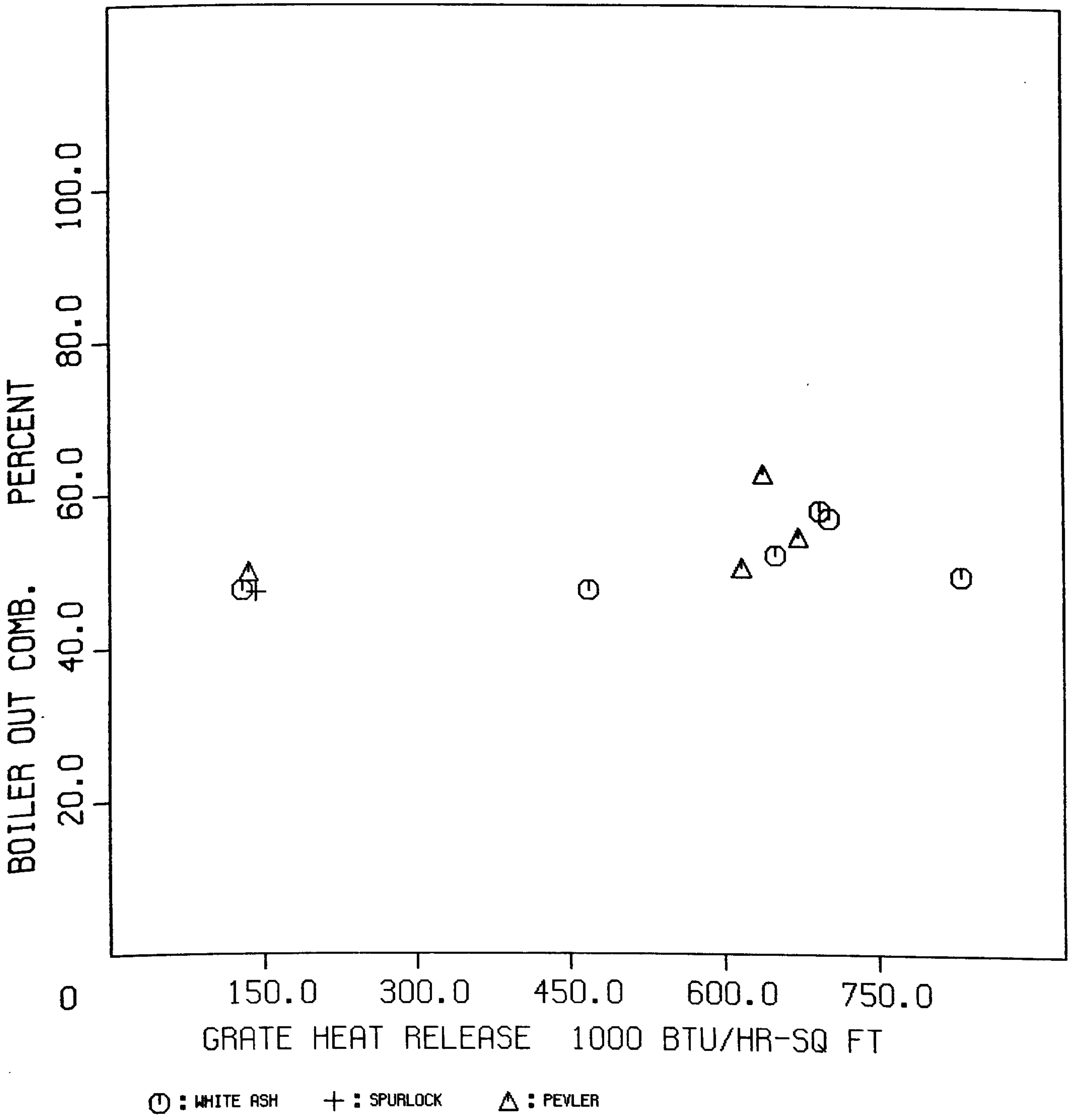


FIG. 5-15
BOILER OUT COMB. VS. GRATE HEAT RELEASE
TEST SITE G

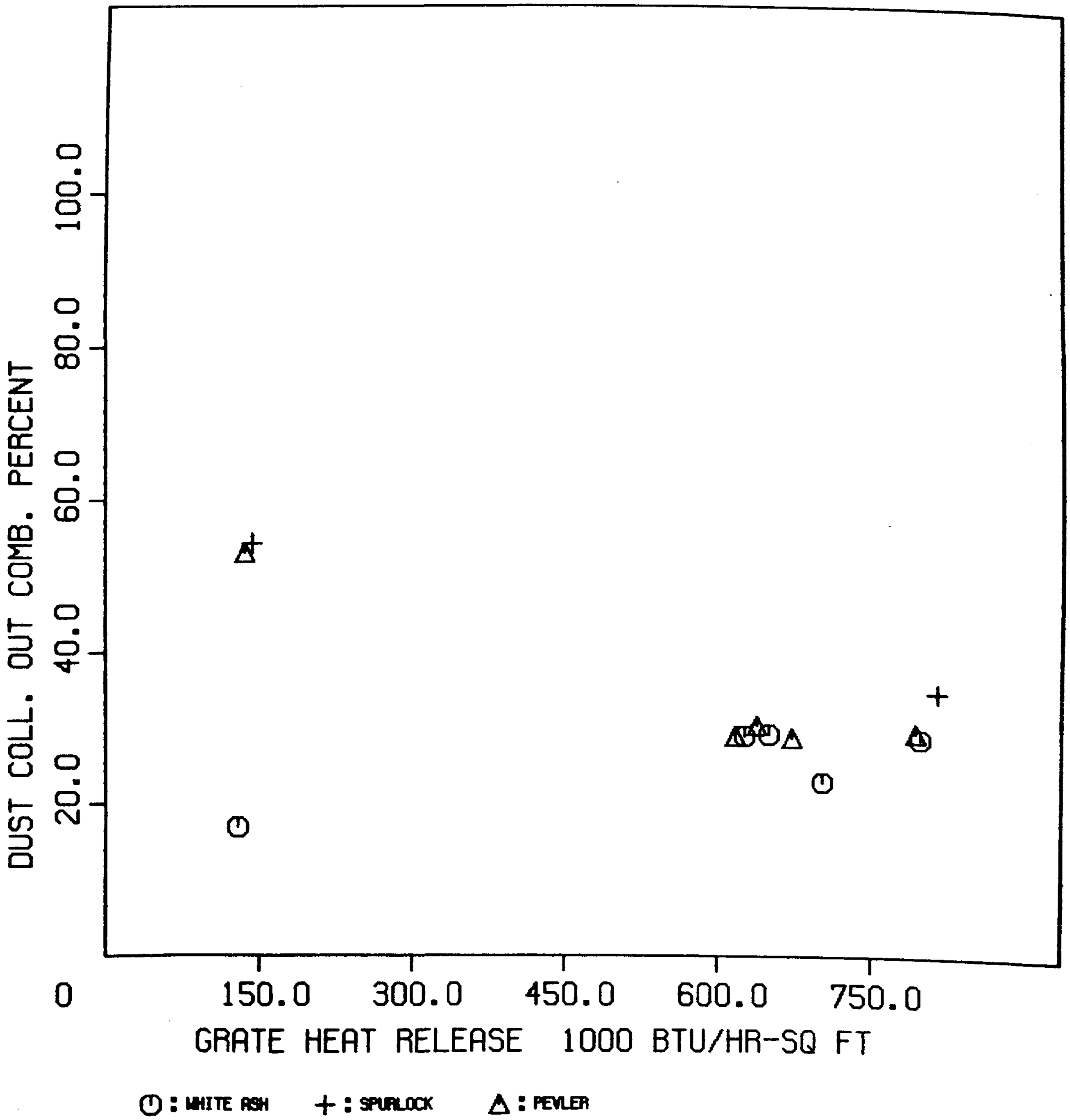


FIG. 5-16

DUST COLL. OUT COMB. VS. GRATE HEAT RELEASE

TEST SITE G

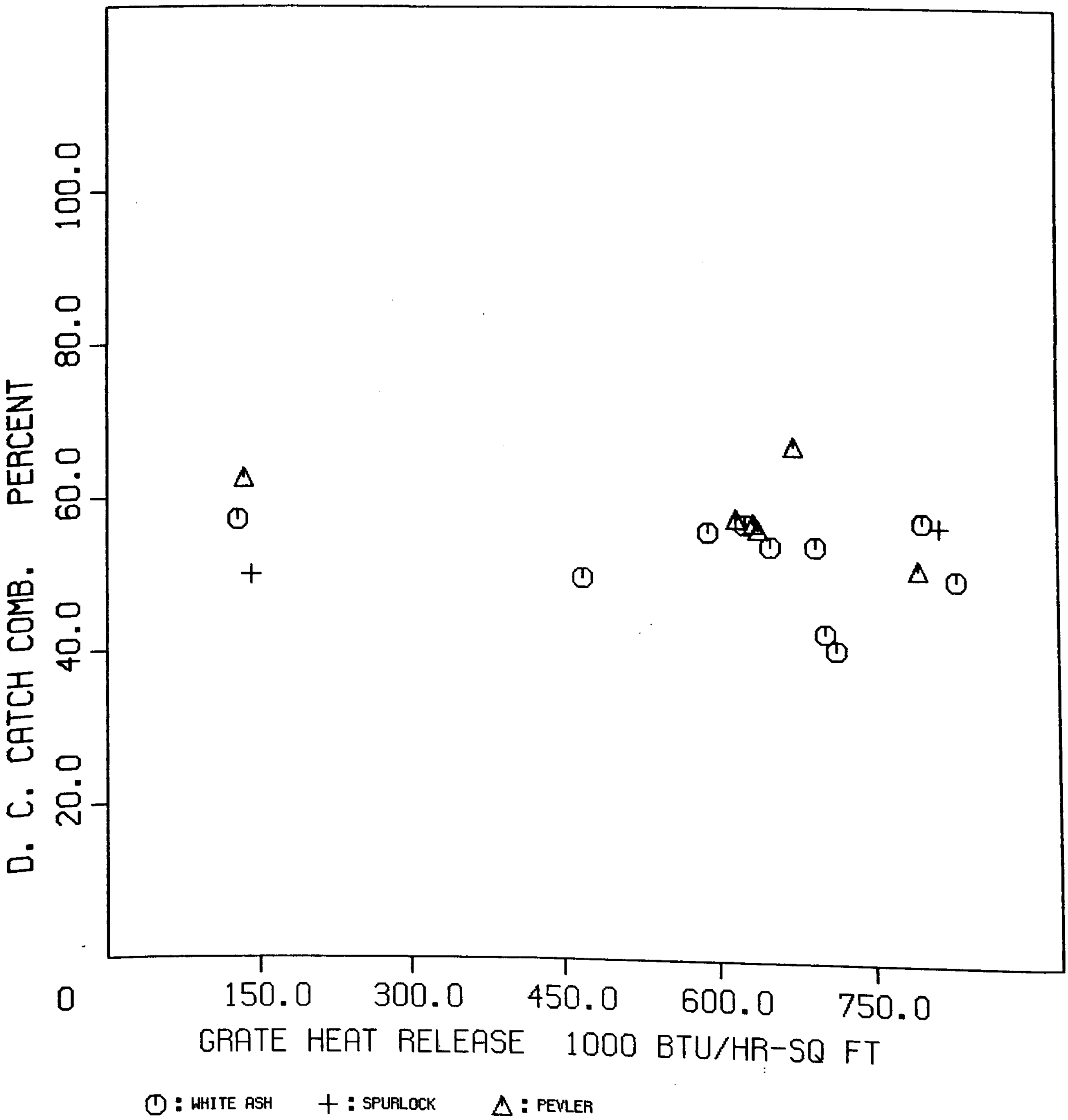


FIG. 5-17
D. C. CATCH COMB. VS. GRATE HEAT RELEASE
TEST SITE G

Coal properties did affect combustible levels. Pevler coal averaged higher ash combustible fractions than the other two coals. Spurlock coal had the lowest combustible fractions in the bottom ash, but the highest combustible fractions in the mechanical collector outlet flyash. This relationship will be examined in greater detail in section 5.4, Coal Properties.

5.3.6 Boiler Efficiency vs Grate Heat Release

Boiler efficiency was determined using the ASME heat loss method for all tests which included a particulate mass loading determination. The test data, plotted in Figure 5-18, shows a general increase in efficiency as grate heat release increases. The reason for this increase in efficiency is illustrated in Table 5-10. It is seen that dry gas loss is a major determining factor.

TABLE 5-10

BOILER EFFICIENCY VS LOAD

	Average Heat Losses				Boiler
	Dry Gas	Combustibles	Radiation	Other	Efficiency
100% Load	13.1	4.3	0.5	6.3	75.8
80% Load	13.9	4.8	0.7	6.1	74.5
17% Load	23.8	1.9	3.1	5.7	65.5

The measured heat losses are compared with the manufacturers predicted heat losses at 100% and 80% of design capacity in Table 5-11. The largest discrepancy is in the dry gas heat loss category where predicted heat loss is several percent lower than measured heat loss.

The primary reason for this discrepancy is that design excess air was not met on this unit. The manufacturers predicted performance is based on 31% excess air whereas the measured excess air ranged from 43 to 69% excess air. The predicted vs measured performance data are shown in Table 5-12.

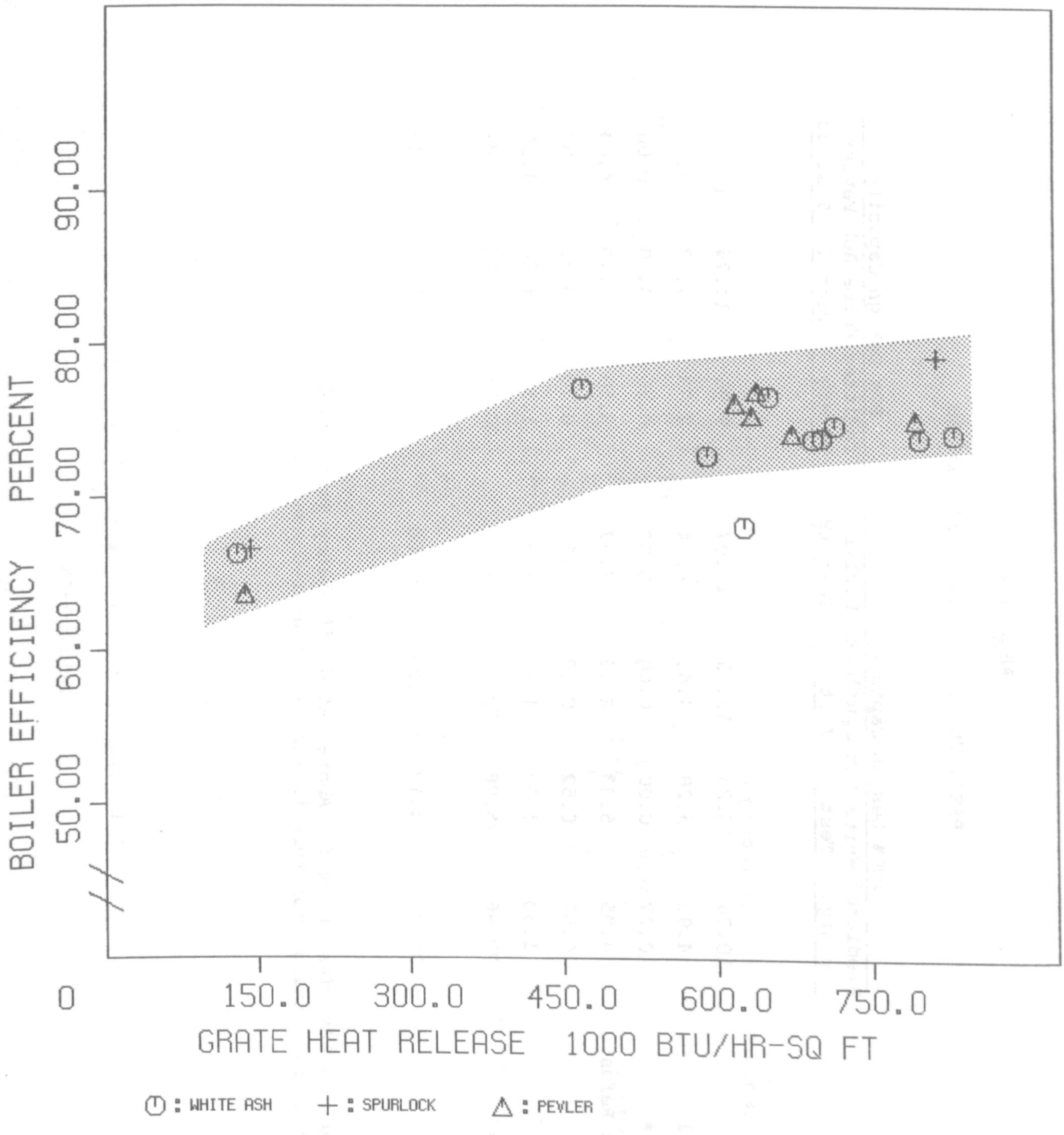


FIG. 5-18
BOILER EFFICIENCY VS. GRATE HEAT RELEASE
TEST SITE G

TABLE 5-11

PREDICTED VS MEASURED HEAT LOSSES

	100% Design Capacity				80% Design Capacity		
	Predicted by Mfg.	White Ash Test 5	Spurlock Test 8	Pevler Test 18	Predicted by Mfg.	White Ash Test 2	Pevler Test 23
HEAT LOSSES, %							
Dry Gas	10.74	13.25	12.25	13.07	9.95	14.74	12.95
H_2 & H_2O in Fuel	4.93	5.28	4.40	4.94	4.78	4.67	4.70
Moisture in Air*	0.27	0.00	0.00	0.00	0.25	0.00	0.00
Combustibles in Refuse	4.95	5.33	2.12	4.87	3.50	4.70	4.00
Radiation	0.57	0.52	0.53	0.54	0.73	0.62	0.69
Unmeasured	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Heat Loss	22.96	25.88	20.80	24.92	20.78	26.23	23.84
BOILER EFFICIENCY	77.04	74.12	79.20	75.08	79.22	73.77	76.16

*KVB used the ASME Test Form for Abbreviated Efficiency Test (PR 4.1) which does not include moisture in air as a measured heat loss.

TABLE 5-12

PREDICTED VS MEASURED PERFORMANCE DATA

	100% Design Capacity				80% Design Capacity		
	Predicted by Mfg.	White Ash Test 5	Spurlock Test 8	Pevler Test 18	Predicted by Mfg.	White Ash Test 2	Pevler Test 23
Steam Flow, lbs/hr	75,000	76,278	74,690	72,857	60,000	63,750	56,667
Steam Pressure, psig	160	137	140	138	160	138	139
Steam Temperature, °F	Sat	Sat	Sat	Sat	Sat	Sat	Sat
Feedwater Temp., °F*	212	--	--	--	212	--	--
Gas Temp Blr Out, °F	530	539	511	526	490	531	515
Excess Air, %	31	48	43	53	31	69	58
Boiler Efficiency, %	77.04	74.12	79.20	75.08	79.22	73.77	76.16
As Fired Coal Analysis							
Moisture, %	6.01	7.56	2.91	5.04	6.01	4.55	4.56
Ash, %	6.68	10.05	4.27	8.94	6.68	9.44	7.15
Volatile, %	34.54	31.80	38.62	34.03	34.54	35.68	36.83
Fixed Carbon, %	51.70	50.59	54.20	51.99	51.70	50.33	51.46
Btu/lb	12834	12036	13922	12488	12834	12639	12830
Sulfur, %	1.07	0.85	1.46	0.69	1.07	0.72	0.83

* -- means data was not recorded

5.4 COAL PROPERTIES

Three coals were tested in Boiler G. These coals are identified in this report as White Ash, Spurlock and Pevler. This section describes the chemical and physical properties of these three coals, and discusses their observed influence on boiler emissions and efficiency.

5.4.1 Chemical Composition of the Coals

Representative coal samples were obtained from access doors immediately above each of the unit's three coal feeders as described in section 4.5. Each of these coal samples was given a proximate analysis. In addition, selected samples of each coal were given an ultimate analysis, and tested for ash fusion temperature, Hardgrove grindability index, free swelling index, and mineral composition of the ash.

The moisture, ash and sulfur content of the three coals are compared on a heating value basis in Table 5-13. Such a comparison is often more meaningful than percentage by weight. This table shows that the White Ash and Pevler coals were very similar while the Spurlock coal was lower in both moisture and ash, and higher in sulfur content.

TABLE 5-13

COAL PROPERTIES CORRECTED TO A CONSTANT 10^6BTU BASIS

		White Ash	Spurlock	Pevler
Moisture,	lbs/10^6Btu	3.5	2.2	3.6
Ash,	lbs/10^6Btu	6.3	3.2	5.7
Sulfur,	lbs/10^6Btu	0.61	0.95	0.59

The coal analysis for each individual sample are tabulated in Tables 5-14, 5-15, 5-16 and 5-17.

TABLE 5-14

FUEL ANALYSIS - WHITE ASH
TEST SITE G

TEST NO.	02	03	04	05	06	09	10	15	16	17	COMP	AVG	STD DEV
PROXIMATE (as rec)													
% Moisture	4.55	4.40	5.57	7.56	3.16	4.32	3.90	4.22	4.02	3.88	4.00	4.56	1.22
% Ash	9.44	5.91	7.65	10.05	7.05	7.24	8.57	9.50	7.63	7.41	10.03	8.05	1.30
% Volatile	35.68	35.79	34.66	31.80	37.23	36.72	34.89	34.95	34.86	35.33	36.46	35.19	1.46
% Fixed Carbon	50.33	53.90	52.12	50.59	52.56	51.72	52.64	51.33	53.49	53.38	49.51	52.21	1.22
Btu/lb	12639	13224	12864	12036	13254	13117	12837	12649	12965	13103	12635	12869	365
% Sulfur	0.72	0.81	0.60	0.85	0.86	0.81	0.93	0.68	0.74	0.82	0.77	0.78	0.10
ULTIMATE (as rec)													
% Moisture						4.32		4.22			4.00	4.27	0.07
% Carbon						73.76		71.62			71.40	72.69	1.51
% Hydrogen						4.90		4.66			4.60	4.78	0.17
% Nitrogen						0.84		1.12			0.98	0.98	0.20
% Chlorine						0.12		0.07			0.10	0.10	0.04
% Sulfur						0.81		0.68			0.77	0.75	0.09
% Ash						7.24		9.50			10.03	8.37	1.60
% Oxygen (diff)						8.01		8.13			8.12	8.07	0.08
ASH FUSION (reducing)													
Initial Deformation						2700+		2700+			2700+		
Soft (H=W)						2700+		2700+			2700+		
Soft (H=1/2W)						2700+		2700+			2700+		
Fluid						2700+		2700+			2700+		
HARDGROVE GRINDABILITY						41		41			38	41.00	0.00
FREE SWELLING INDEX						2-1/2		2			1-1/2	2.25	0.35

TABLE 5-15

FUEL ANALYSIS - SPURLOCK
TEST SITE G

TEST NO.	07	08	COMP	AVG	STD DEV
PROXIMATE (as rec)					
% Moisture	3.12	2.91	3.32	3.02	0.15
% Ash	4.57	4.27	6.56	4.42	0.21
% Volatile	39.33	38.62	39.20	38.98	0.50
% Fixed Carbon	52.98	54.20	50.92	53.59	0.86
Btu/lb	13797	13922	13397	13860	88
% Sulfur	1.16	1.46	1.31	1.31	0.21
ULTIMATE (as rec)					
% Moisture			3.32		
% Carbon			74.59		
% Hydrogen			5.11		
% Nitrogen			1.12		
% Chlorine			0.18		
% Sulfur			1.31		
% Ash			6.56		
% Oxygen (diff)			7.81		
ASH FUSION (reducing)					
Initial Deformation			2420°F		
Soft (H=W)			2650°F		
Soft (H=1/2W)			2680°F		
Fluid			2700°F+		
HARDGROVE GRINDABILITY			37		
FREE SWELLING INDEX			2-1/2		

TABLE 5-16

FUEL ANALYSIS - PEVLER
TEST SITE G

TEST NO.	18	19	20	22	23	24	COMP	AVG	STD DEV
PROXIMATE (as rec)									
% Moisture	5.04	4.53	4.81	4.69	4.56	3.93	4.45	4.59	0.37
% Ash	8.94	6.52	6.95	7.17	7.15	7.19	7.24	7.32	0.83
% Volatile	34.03	36.91	36.47	37.65	36.83	35.87	37.07	36.29	1.25
% Fixed Carbon	51.99	52.04	51.77	50.49	51.46	53.01	51.24	51.79	0.82
Btu/lb	12488	12989	12860	12881	12830	12943	12912	12832	178
% Sulfur	0.69	0.85	0.69	0.78	0.83	0.69	0.65	0.76	0.07
ULTIMATE (as rec)									
% Moisture			4.81				4.45		
% Carbon			72.43				72.91		
% Hydrogen			4.90				4.86		
% Nitrogen			1.04				0.96		
% Chlorine			0.05				0.05		
% Sulfur			0.69				0.65		
% Ash			6.95				7.24		
% Oxygen (diff)			9.13				8.88		
ASH FUSION (reducing)									
Initial Deformation			2700+°F				2700+°F		
Soft (H=W)			2700+°F				2700+°F		
Soft (H=1/2W)			2700+°F				2700+°F		
Fluid			2700+°F				2700+°F		
HARDGROVE GRINDABILITY			35				37		
FREE SWELLING INDEX			2-1/2				1-1/2		

TABLE 5-17

MINERAL ANALYSIS OF COAL ASH
TEST SITE G

Coal Test No.	White Ash 9	White Ash 15	White Ash Comp	Spurlock Comp	Pevler 20	Pevler Comp
Silica, SiO_2	51.40	52.83	54.45	43.26	49.62	52.38
Alumina, Al_2O_3	32.80	31.52	29.56	30.37	37.75	36.61
Titania, TiO_2	1.34	1.58	1.29	1.21	1.88	1.96
Ferric Oxide, Fe_2O_3	6.99	6.84	7.15	13.50	4.52	3.75
Lime, CaO	2.11	1.19	1.54	3.43	1.32	1.19
Magnesia, MgO	1.02	1.09	0.98	1.32	0.84	0.77
Potassium Oxide, K_2O	2.23	2.47	2.69	2.05	1.53	1.61
Sodium Oxide, Na_2O	0.52	0.48	0.44	0.61	0.31	0.26
Sulfur Trioxide, SO_3	0.99	0.80	0.57	3.61	0.56	0.65
Phos. Pentoxide, P_2O_5	0.18	0.14	0.18	0.19	0.15	0.16
Strontium Oxide, SrO	0.05	0.08	0.00	0.10	0.07	0.06
Barium Oxide, BaO	0.24	0.23	0.24	0.26	0.12	0.13
Manganese Oxide, Mn_3O_4	0.01	0.02	0.03	0.02	0.01	0.00
Undetermined	0.07	0.73	0.88	0.07	1.32	0.47
Alkalies as Na_2O (dry basis)	0.15	0.21	0.24	0.13	0.10	0.10
Silica Value	83.55	85.28	84.92	70.33	88.13	90.17
Base: Acid Ratio	0.15	0.14	0.15	0.28	0.10	0.08
T_{250} Temperature	2820°F	2845°F	2825°F	2575°F	2900°F+	2900°F+
Fouling Index	0.08	0.07	0.03	0.17	0.03	0.02
Slagging Index	0.13	0.10	0.12	0.38	0.07	0.05
% Pyritic Sulfur	0.12	0.05	0.09	0.47	0.10	0.08
% Sulfate Sulfur	0.03	0.04	0.05	0.04	0.00	0.00
% Organic Sulfur	0.66	0.59	0.63	0.80	0.59	0.57

5.4.2 Coal Size Consistency

Coal size consistency was not varied for test purposes at Site G but it was measured. The individual coal samples were screened at the site using 1", 1/2", 1/4", #8 and #16 square mesh screens. The results of these screenings are presented in Table 5-18. Spurlock coal, which had the lowest ash content of the three coals tested, also had the lowest percentage of fines.

The standard deviation of the coal size consistency measurements are compared with the ABMA recommended limits for spreader stokers in Figures 5-19, 5-20 and 5-21. The size consistency of all three coals is within the ABMA recommended limits at sizes below 1/2 inch. The fact that the measured size distribution curves extend outside the ABMA recommended limits above about 1/2 inch indicates only that the top size on these coals was close to one inch whereas the ABMA limits are based on a coal having a top size of about 1-1/4 inch. This is not considered an undesirable property.

5.4.3 Effect of Coal Properties on Emissions and Efficiency

The influence that changing coals -- from White Ash to Spurlock to Pevler -- had on boiler emissions and efficiency is discussed below. Frequent references are made to figures in Section 5.3, Excess Oxygen and Grate Heat Release, which illustrate the differences between the two coals.

Excess Oxygen Operating Conditions. In general, all three coals were tested under similar excess oxygen conditions. There was no data indicating that one coal could be fired at consistently lower excess oxygen conditions than any other coal. Figure 5-3 shows the oxygen levels under which the various tests were run for each coal.

Particulate Mass Loading. The effect of coal properties on this emission is illustrated in Figure 5-4 and Table 5-19. At full load, the low ash low fines Spurlock coal produced the lowest boiler outlet particulate loading. The high ash high fines White Ash coal produced the highest full load boiler outlet particulate loading. At 80% load and base load conditions there

TABLE 5-18

AS FIRED COAL SIZE CONSISTENCY
TEST SITE G

	Test No.	PERCENT PASSING STATED SCREEN SIZE 1"	1/2"	1/4"	#8	#16
WHITE ASH	02	97.5	66.9	39.5	20.3	12.7
	03	99.3	64.3	30.7	13.7	8.9
	04	96.9	71.0	36.3	14.8	5.8
	05	99.4	78.3	43.0	17.2	7.5
	06	99.2	82.4	49.8	26.6	16.1
	09	99.0	65.9	32.2	15.0	8.1
	10	98.9	70.5	39.3	21.8	15.3
	15	98.5	79.5	46.6	24.7	15.2
	16	98.3	80.6	47.8	22.8	13.0
	17	95.6	75.0	43.0	23.0	15.0
	Composite	98.2	77.5	46.6	25.3	16.7
	Average	98.3	73.4	40.8	20.0	11.8
SPURLOCK	07	99.6	51.0	24.2	14.8	10.6
	08	100.0	49.0	19.1	11.3	8.3
	Composite	99.8	50.4	22.3	13.2	9.5
	Average	99.8	50.0	21.7	13.1	9.5
PEVLER	18	98.6	86.3	51.9	24.4	14.3
	19	95.7	67.8	33.6	15.3	9.9
	20	96.5	64.4	32.1	14.7	9.6
	22	94.2	68.9	31.9	13.2	8.0
	23	98.6	79.1	32.3	12.6	8.0
	24	95.6	69.1	31.5	14.2	9.7
	Composite	94.6	68.3	32.1	14.3	9.1
	Average	96.5	72.6	35.6	15.7	9.9

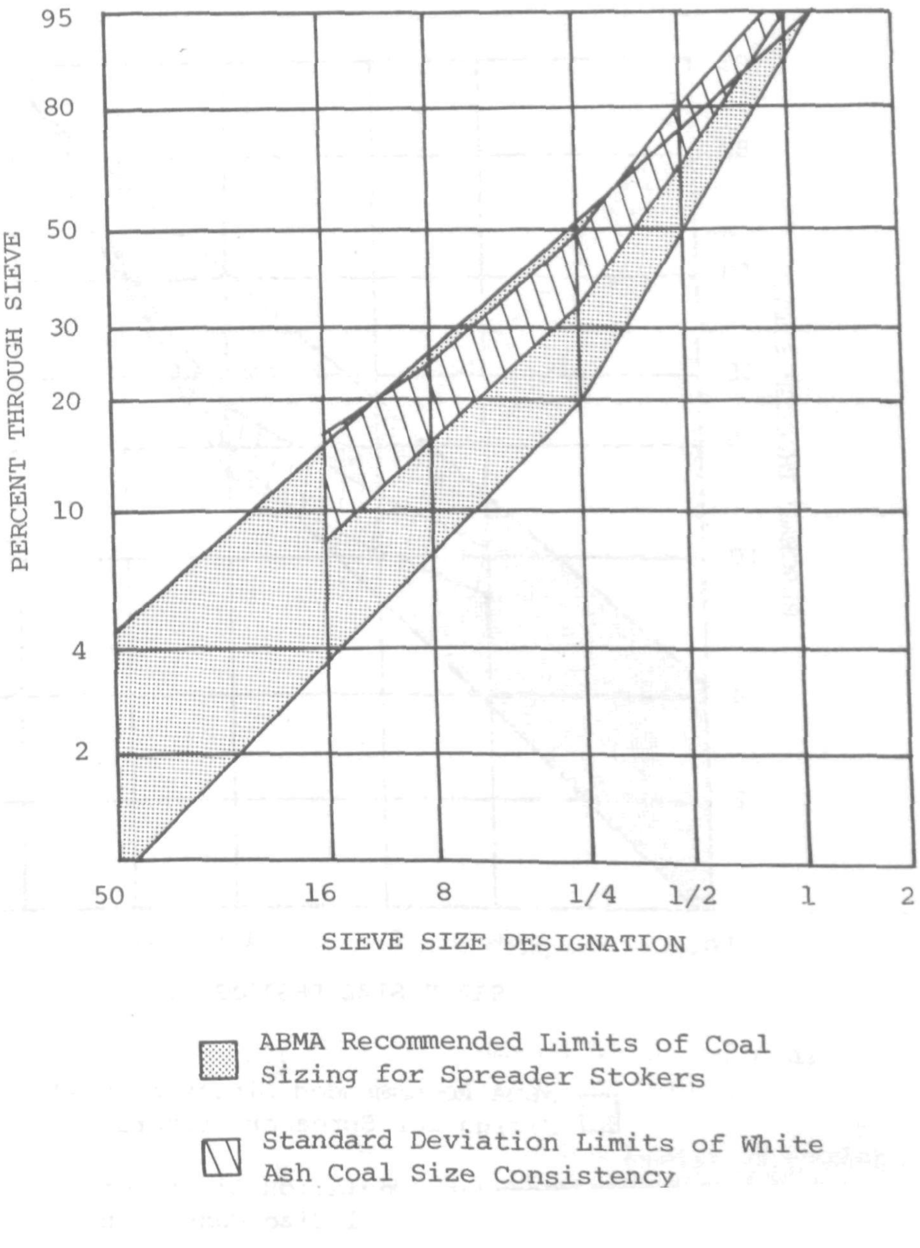


FIGURE 5-19. Size Consistency of "As Fired" White Ash Coal vs ABMA Recommended Limits of Coal Sizing for Spreader Stokers - Test Site G

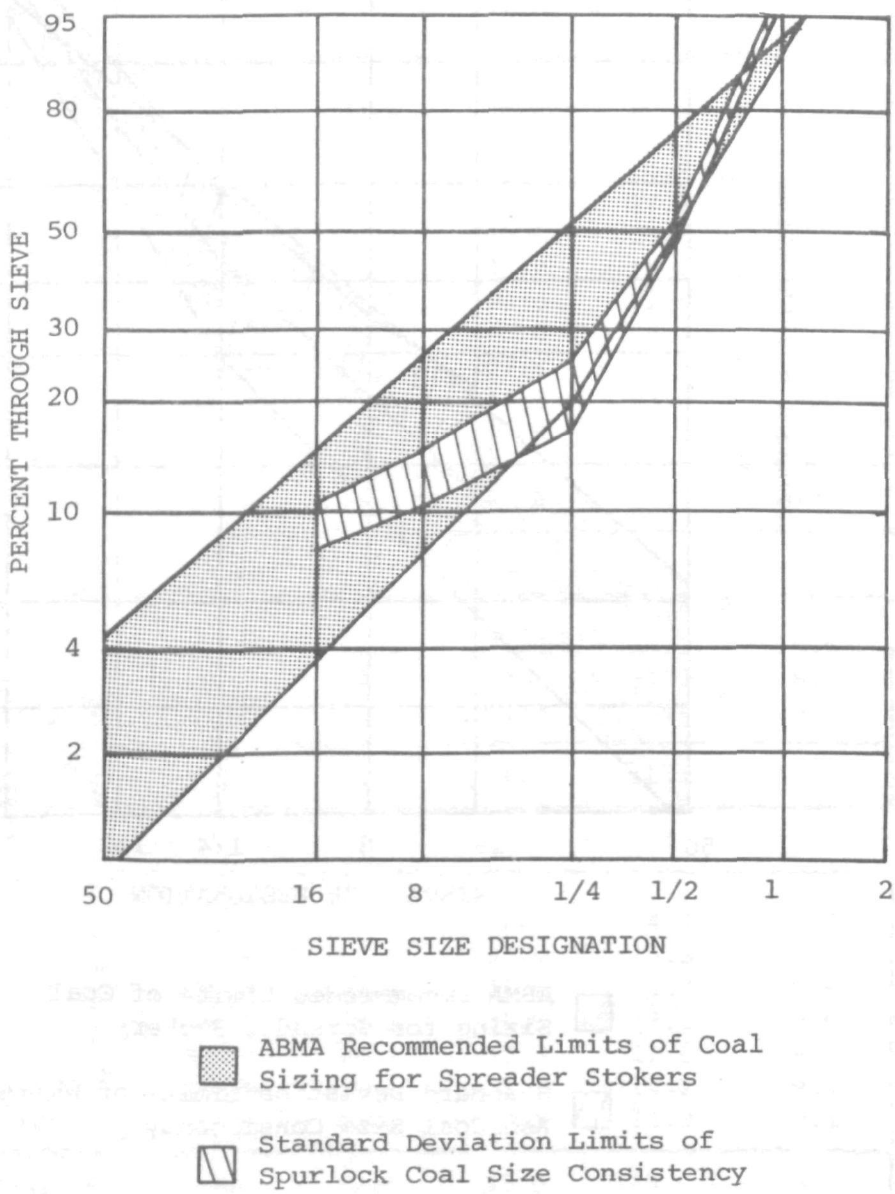


FIGURE 5-20. Size Consistency of "As Fired" Spurlock Coal vs ABMA Recommended Limits of Coal Sizing for Spreader Stokers - Test Site G

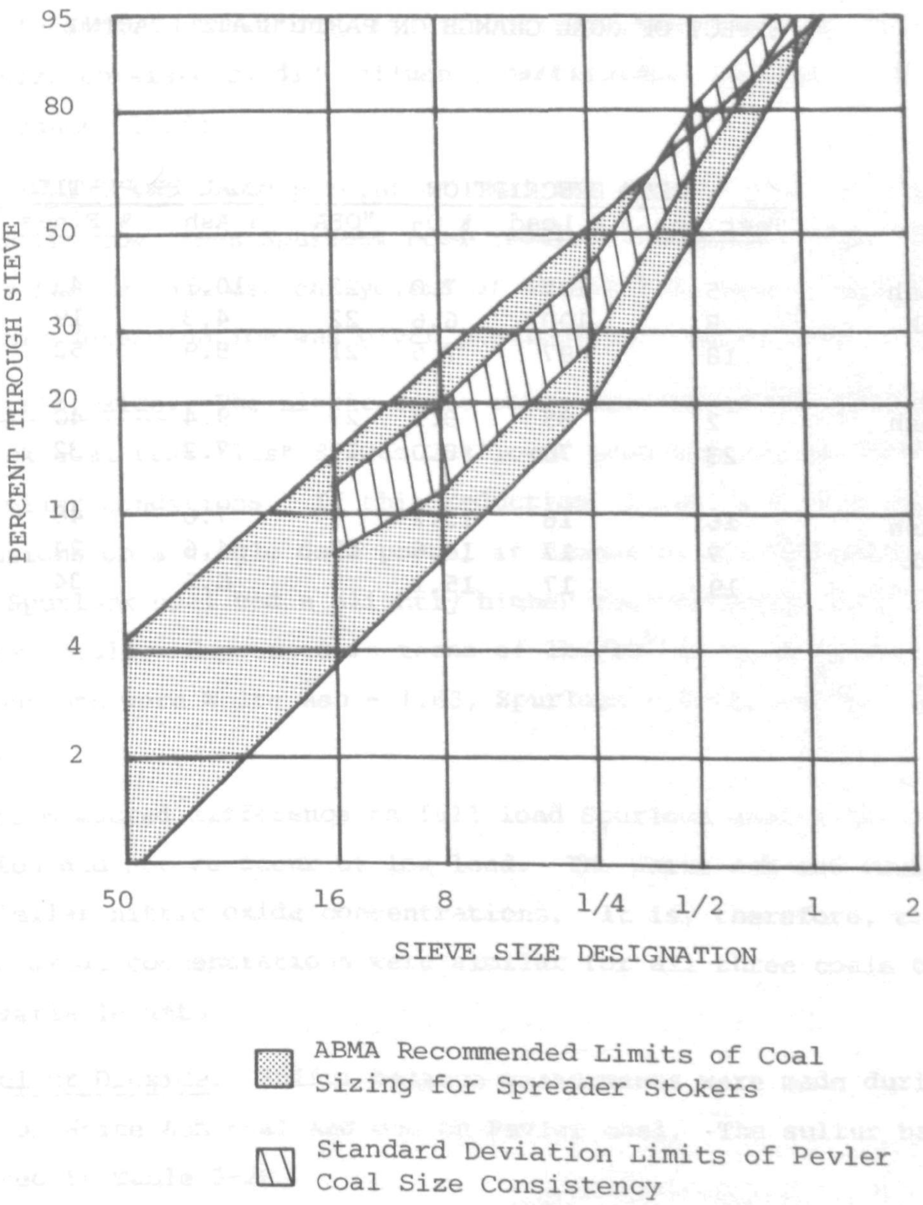


FIGURE 5-21. Size Consistency of "As Fired" Pevler Coal vs ABMA Recommended Limits of Coal Sizing for Spreader Stokers - Test Site G

TABLE 5-19

EFFECT OF COAL CHANGE ON PARTICULATE LOADING

Coal	TEST DESCRIPTION				COAL PROPERTIES		BOILER OUT PARTICULATE
	Test No.	% Load	% O_2	"OFA	% Ash	% Fines	$lbs/10^6 Btu$
White Ash	5	102	7.0	22	10.1	43	6.8
Spurlock	8	100	6.6	22	4.3	19	2.9
Pevler	18	97	7.5	21	8.9	52	4.8
White Ash	2	85	8.9	23	9.4	40	4.3
Pevler	23	76	8.0	19	7.2	32	4.6
White Ash	16	16	15.2	7	7.6	48	2.3
Spurlock	7	17	14.6	15	4.6	24	2.1
Pevler	19	17	15.1	5	6.5	34	2.1

were no differences between the White Ash and Pevler coal particulate loadings. Only under swing load conditions did the White Ash coal produce significantly greater particulate loadings. At 17% load all three coals gave similar particulate loadings. Therefore, it is concluded that the coal properties of ash and size consistency did influence particulate loadings at full load, but not at reduced loads.

Ash Carryover. The percent of coal ash carried over as flyash was greatest for the low fines Spurlock coal (50%). The higher fines White Ash and Pevler coals had average ash carryovers of 42 and 34%, respectively. The basis for this determination was given previously in Table 5-8.

Nitric Oxide. The nitric oxide concentration of the single full load Spurlock coal test (Test 8) was 20% lower than that of the other two coals at similar conditions. If this reduction is real (it is a risk to base conclusions on a single data point) it cannot be attributed to fuel nitrogen. Spurlock coal had a slightly higher fuel nitrogen content than the other two coals. Expressed in terms of $lbs/10^6 Btu$ as NO_2, the coal's nitrogen contents were White Ash - 1.63, Spurlock - 1.73, and Pevler - 1.67 $lbs/10^6 Btu$.

The measured difference in full load Spurlock coal nitric oxide concentration did not re-occur at low load. The White Ash and Pevler tests produced similar nitric oxide concentrations. It is, therefore, concluded that nitric oxide concentrations were similar for all three coals tested based on available data.

Sulfur Dioxide. Sulfur balance measurments were made during three tests, two on White Ash coal and one on Pevler coal. The sulfur balance data are presented in Table 5-20.

TABLE 5-20

SULFUR BALANCE ON BOILER G

	Sulfur in Fuel lbs/10^6Btu as SO_2	Sulfur in Flue Gas lbs/10^6Btu as SO_2	Sulfur in Bottom Ash lbs/10^6Btu as SO_2	Sulfur in Flyash lbs/10^6Btu as SO_2
White Ash (Test 9)	1.235	1.208	0.004	0.065
White Ash (Test 15)	1.075	1.056	0.009	0.055
Pevler (Test 20)	1.073	1.049	0.006	0.032

The sulfur balance was good. Sulfur output was between one and 4% greater than sulfur input which is within expected measurement accuracy for this type of test. Sulfur retention in the ash was 5.6% and 6.0% for the White Ash coal tests, and 3.5% for the Pevler coal tests. Percent conversion of fuel sulfur to SO_2 and SO_3 in the flue gas can be obtained in two ways. The indirect method, i.e., comparing the first two columns in Table 5-20, yields conversion efficiencies of 97.8, 98.2 and 97.8%, respectively for Tests 9, 15 and 20. Perhaps a more accurate method is to subtract the sulfur retained in the ash from the sulfur input. This direct method yields conversion efficiencies of 94.4, 94.0 and 96.5%, respectively for the same tests.

Combustibles in the Ash. Percent combustibles in the bottom ash and in the flyash showed some correlation to coal. These correlations are best illustrated in Figure 5-14, 5-15, 5-16 and 5-17 of section 5.3. The average combustible data for all tests above 50% load are given in Table 5-21.

The low ash, low fines and low moisture Spurlock coal had the lowest combustible fraction in the bottom ash (Figure 5-14) but the highest combustible fraction in the dust collector outlet flyash (Figure 5-16). Pevler coal on the other hand, had the highest bottom ash fraction (Figure 5-14) and dust collector hopper fraction (Figure 5-17). The effect of coal change in combustibles was not great and no mechanism for the observed correlations is proposed.

TABLE 5-21

AVERAGE PERCENT COMBUSTIBLE IN ASH AT LOADS ABOVE 50%

	Bottom Ash	Boiler Out Flyash	D.C. Out Flyash	D.C. Hopper Flyash
White Ash	9	53	27	51
Spurlock	6	--	35	57
Pevler	14	56	29	58

Boiler Efficiency. Boiler efficiency was highest while burning Spurlock coal because of a lower combustible heat loss. This is probably related to coal properties. Moisture related heat losses on the other hand were similar for all three coals. Data are presented in Figure 5-18 of section 5.3 and in Table 5-22.

TABLE 5-22

BOILER EFFICIENCY VS COAL

	BOILER HEAT LOSSES, %				
	Dry Gas	Moisture Related	Combus-tible	Other	BOILER EFFICIENCY, %
White Ash Coal (Test 5)	13.3	5.3	5.3	2.0	74.1
Spurlock Coal (Test 8)	12.3	4.4	2.1	2.0	79.2
Pevler Coal (Test 18)	13.1	4.9	4.9	2.0	75.1

5.5 PARTICLE SIZE DISTRIBUTION OF FLYASH

Ten particle size distribution determinations were made at the boiler outlet on Boiler G. These determinations were made using a Bahco classifier, a Brink cascade impactor, and a SASS cyclone train. Test conditions for the ten particle size distribution tests are described in Table 5-23.

The test results are presented in Table 5-24, and in Figures 5-22, 5-23 and 5-24. The test results are grouped by sample methodology (i.e., Brink, Bahco or SASS) because each methodology may influence the data. A discussion of each method, its advantages and drawbacks, is presented in Section 4. The basic differences are outlined below.

The Bahco classifier sample was collected with a cyclone. As a result, a fraction of the sample (6 to 12%) was not captured and the results are biased such that they indicate fewer particles below about 15 micrometers than there actually were. It is hoped that appropriate corrections can be made to the Bahco data at some future date using the measured cyclone collection efficiency (shown in Table 5-24, last column) and the theoretical cyclone collection efficiencies by particle size.

The Brink and SASS particle size distribution data should be accurate and require no corrections. However, these are single point measurements, whereas the Bahco data was obtained with a 24-point traverse of the duct. Single point samples are suspect for reasons of size stratification within the duct.

Despite the differences in methodologies, there is a degree of validity to the data trends. The measured differences in particle size distribution are often reflected in the multiclone collection efficiencies as shown in Table 5-25. In many cases, the flyash with the lowest percentage of particles below 10 or 3 micrometers was the flyash most efficiently collected in the mechanical dust collector.

The data indicates that flyash from White Ash coal was sized smaller than flyash from Pevler coal and was thus captured more efficiently in the mechanical dust collector.

TABLE 5-23

DESCRIPTION OF PARTICLE SIZE DISTRIBUTION TESTS AT THE BOILER OUTLET TEST SITE G

Test No.	Coal	Load %	O_2 %	Test Description	Particle Size Distribution Methodology Used
5	White Ash	102	7.0	Base Loaded	Bahco - Sieve
8	Spurlock	100	6.6	Base Loaded	Bahco - Sieve
18	Pevler	97	7.5	Base Loaded	Bahco - Sieve
17	White Ash	98	7.4	w/o Reinjection	Bahco - Sieve
4	White Ash	77	10.4	Swing Loaded	Bahco - Sieve
5	White Ash	102	7.0	Base Loaded	Brink Impactor
17	White Ash	98	7.4	w/o Reinjection	Brink Impactor
9	White Ash	72	10.2	Swing Loaded	SASS Gravimetrics
15	White Ash	87	8.7	Swing Loaded	SASS Gravimetrics
20	Pevler	78	9.2	Swing Loaded	SASS Gravimetrics

TABLE 5-24

RESULTS OF PARTICLE SIZE DISTRIBUTION TESTS AT THE BOILER OUTLET TEST SITE G

Test No.	Test Description	Size Distribution % Below 3μm	Size Distribution % Below 10μm	Size Concentration $lb/10^6 Btu$ Below 3μm	Size Concentration $lb/10^6 Btu$ Below 10μm	Sample Collection Efficiency, %
5	Full Load, White Ash Coal- Bahco	1.1	4.5	0.075	0.305	93.4
8	Full Load, Spurlock Coal - Bahco	2.5	7.5	0.073	0.220	87.8
18	Full Load, Pevler Coal - Bahco	2.2	8.8	0.105	0.421	91.2
9	Swing Load,White Ash Coal- SASS	10.4	21.1	--	--	100
15	Swing Load,Spurlock Coal - SASS	8.1	27.5	--	--	100
20	Swing Load, Pevler Coal - SASS	23.0	50.2	--	--	100
5	With Reinjection - Bahco	1.1	4.5	0.075	0.305	93.4
17	Without Reinjection - Bahco	2.5	10.0	0.146	0.586	91.9
5	With Reinjection - Brink	7.2	--	0.489	--	100
17	Without Reinjection - Brink	3.6	--	0.211	--	100
5	Full Load - Bahco	1.1	4.5	0.075	0.305	93.4
4	77% Load - Bahco	2.6	9.2	0.193	0.682	89.1

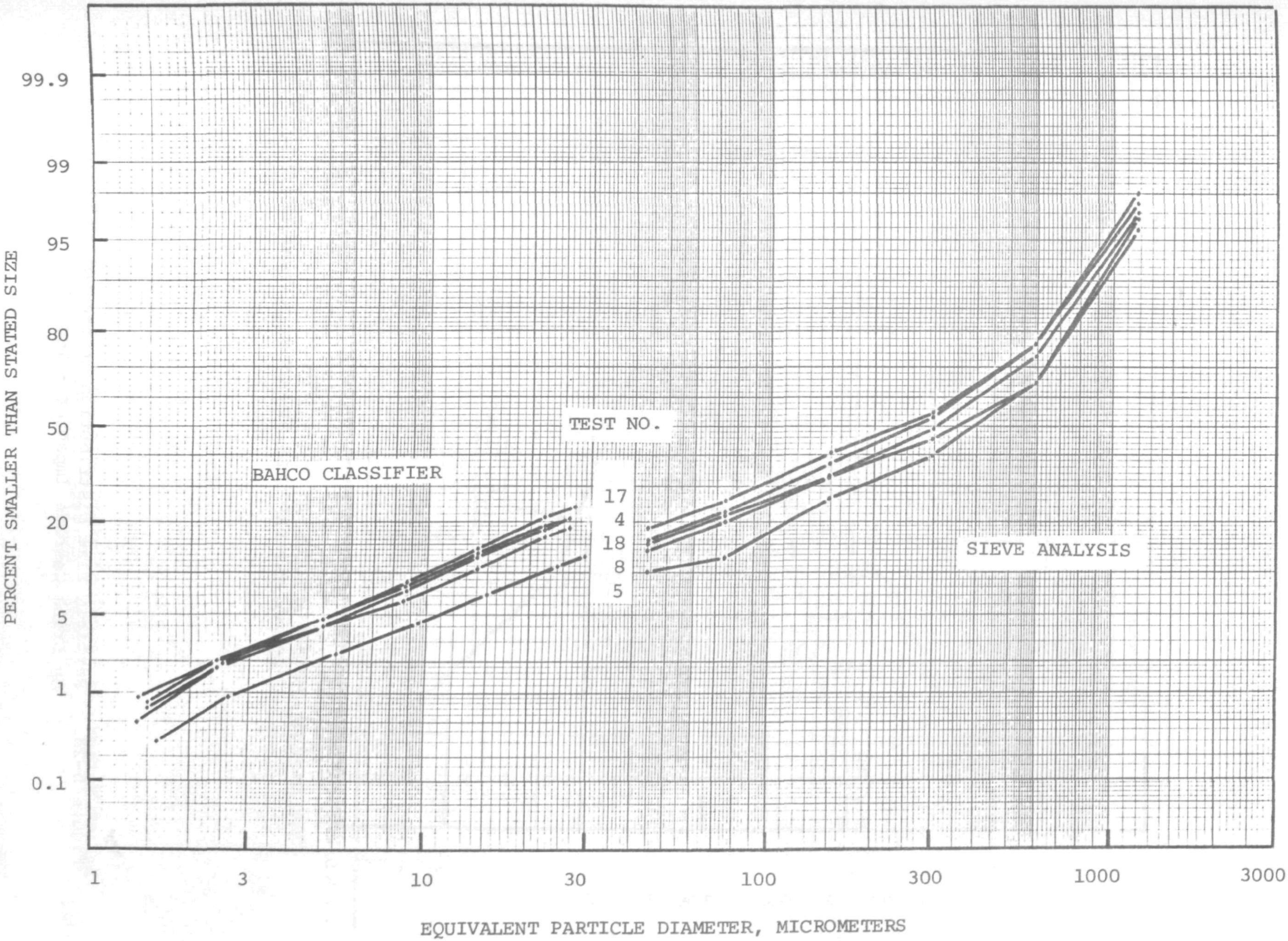


FIGURE 5-22. Particle Size Distribution of the Boiler Outlet Flyash by Bahco Classifier and Sieve Analysis - Test Site G

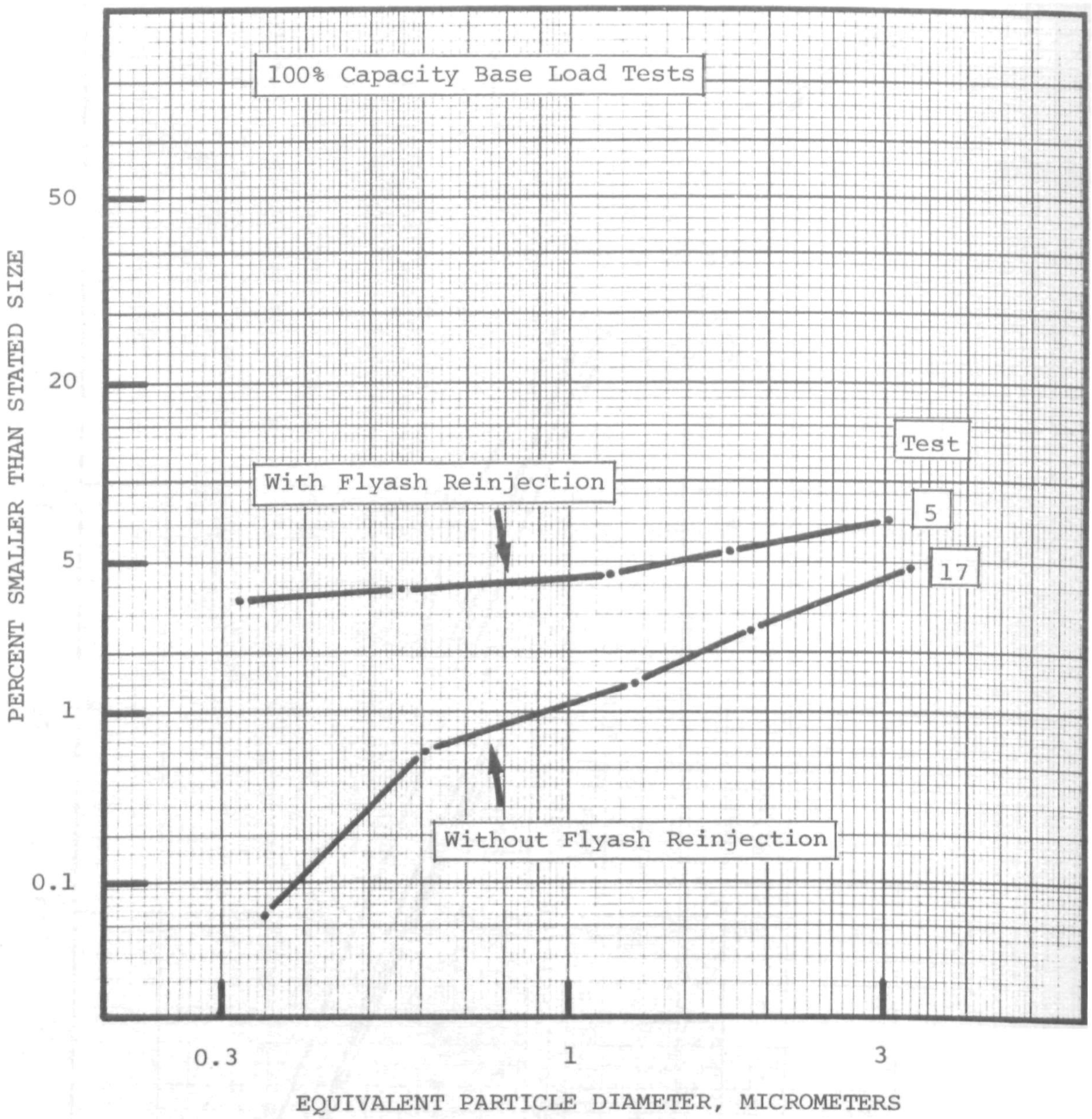


Figure 5-23. Particle Size Distribution at the Boiler Outlet by Brink Cascade Impactor - Test Site G.

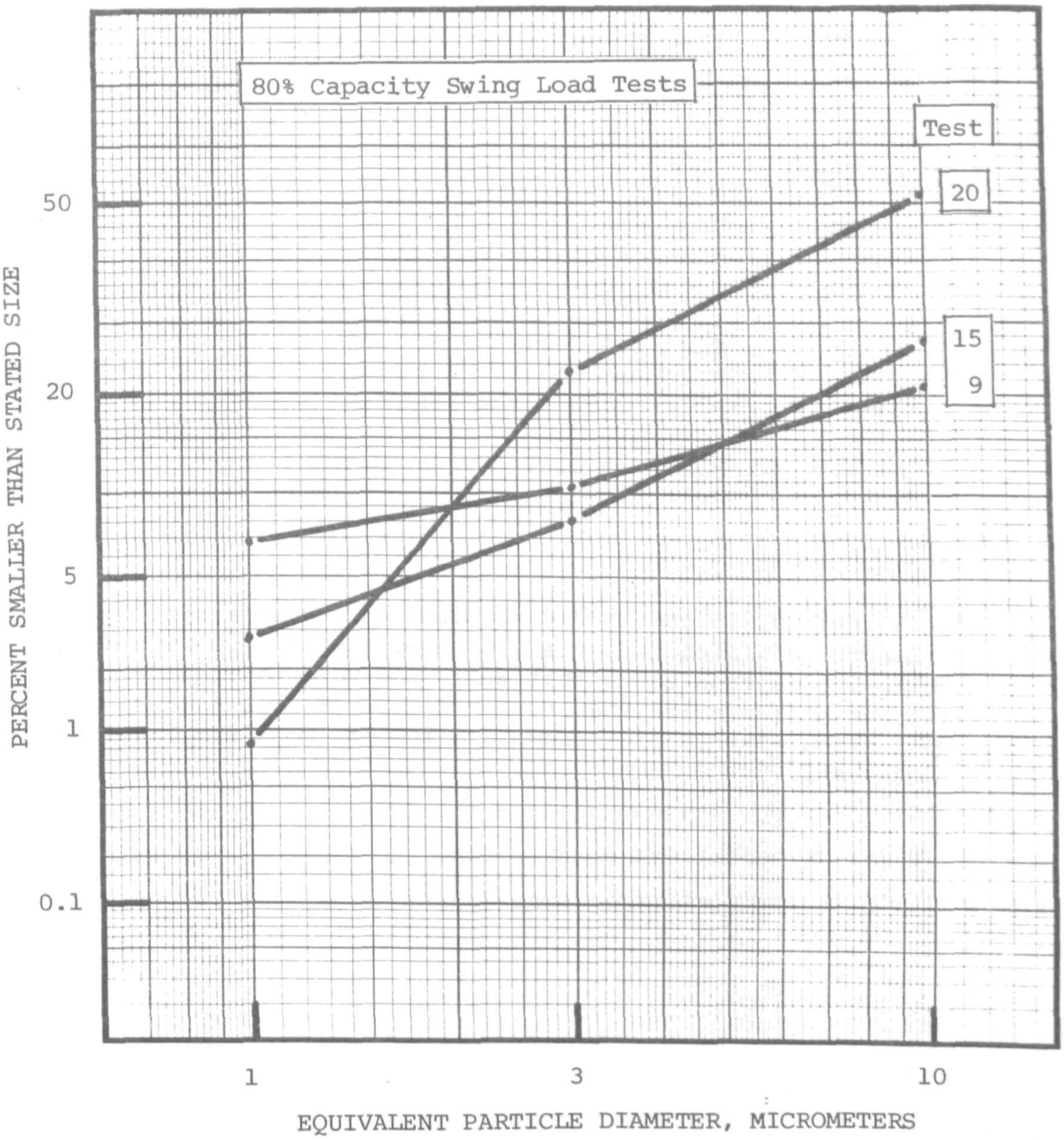


Figure 5-24. Particle Size Distribution at the Boiler Outlet by SASS Gravimetrics - Test Site G.

TABLE 5-25

PARTICLE SIZE DISTRIBUTION
VS DUST COLLECTOR EFFICIENCY

Test No.	Test Methodology	Test Description	% Flyash Below 10μm	Dust Collector Efficiency, %
5	Bahco	White Ash - Full Load	4.5	96.0
8	Bahco	Spurlock Coal - Full Load	7.5	94.3
18	Bahco	Pevler Coal - Full Load	8.8	93.3
9	SASS	White Ash Coal - Swing Load	21.1	97.0 (Test 4)*
15	SASS	White Ash Coal - Swing Load	27.5	92.7 (Test 10)
20	SASS	Pevler Coal - Swing Load	50.2	92.9 (Test 22)
5	Bahco	White Ash Coal - w/Reinjection	4.5	96.0
17	Bahco	White Ash Coal w/o Reinjection	10.0	93.8

*SASS tests 9, 15 and 20 did not include determination of dust collector efficiency, but a glance at Figure 5-25 in the following section shows that White Ash coal averaged higher collection efficiencies than Pevler B coal at this load range. Collection efficiencies shown are for the most similar particulate tests.

5.6 EFFICIENCY OF MULTICLONE DUST COLLECTOR

The collection efficiency of the multiclone dust collector was determined in fifteen tests under various boiler operating conditions. The data were obtained by measuring the particulate loadings simultaneously at the inlet and outlet of the dust collector. The data are presented in Table 5-26 and plotted as a function of grate heat release in Figure 5-25.

At loads above 50% of design capacity, the dust collection efficiency ranged from 92.7% to 97.0% and averaged 94.4%. At the low load of 17% of design steam capacity, the mechanical dust collection efficiency dropped off drastically averaging 63.4%. This is due to the reduced pressure drop across the dust collector at low loads.

5.7 SOURCE ASSESSMENT SAMPLING SYSTEM (SASS)

Three SASS tests were run at Test Site G and two of these were selected for further processing. Test 15 on White Ash coal was a repeat of Test 9 which was suspect due to a procedural error. On Pevler coal, Test 20 was processed.

Process of the SASS sample catches involves combined gas chromatography/mass spectroscopy for total polynuclear content and seven specific polynuclear aromatic hydrocarbons (PAH). These are listed in Table 5-27. All SASS test results will be reported under separate cover at the conclusion of this test program.

TABLE 5-26

EFFICIENCY OF DUST COLLECTOR
TEST SITE G

Test No.	Coal Type	Load %	O_2 %	Particulate Loading $lb/10^6 Btu$ Collector Inlet	Collector Outlet	Collector Efficiency %
02	White Ash	85.0	8.9	4.271	0.222	94.8
03	White Ash	79.6	8.7	4.332	0.220	94.9
04	White Ash	76.7	10.4	7.408	0.221	97.0
05	White Ash	101.7	7.0	6.786	0.274	96.0
06	White Ash	57.4	10.5	4.171	0.129	96.9
07	Spurlock	17.3	14.6	2.139	0.953	55.4
08	Spurlock	99.6	6.6	2.932	0.166	94.3
10	White Ash	86.0	9.7	6.592	0.484	92.7
16	White Ash	15.8	15.2	2.265	0.933	58.8
17	White Ash	97.7	7.4	5.858	0.364	93.8
18	Pevler	97.1	7.5	4.783	0.320	93.3
19	Pevler	16.6	15.1	2.057	0.495	75.9
22	Pevler	82.4	9.1	4.720	0.334	92.9
23	Pevler	75.6	8.0	4.567	0.320	93.0
24	Pevler	78.3	7.3	4.003	0.260	93.5

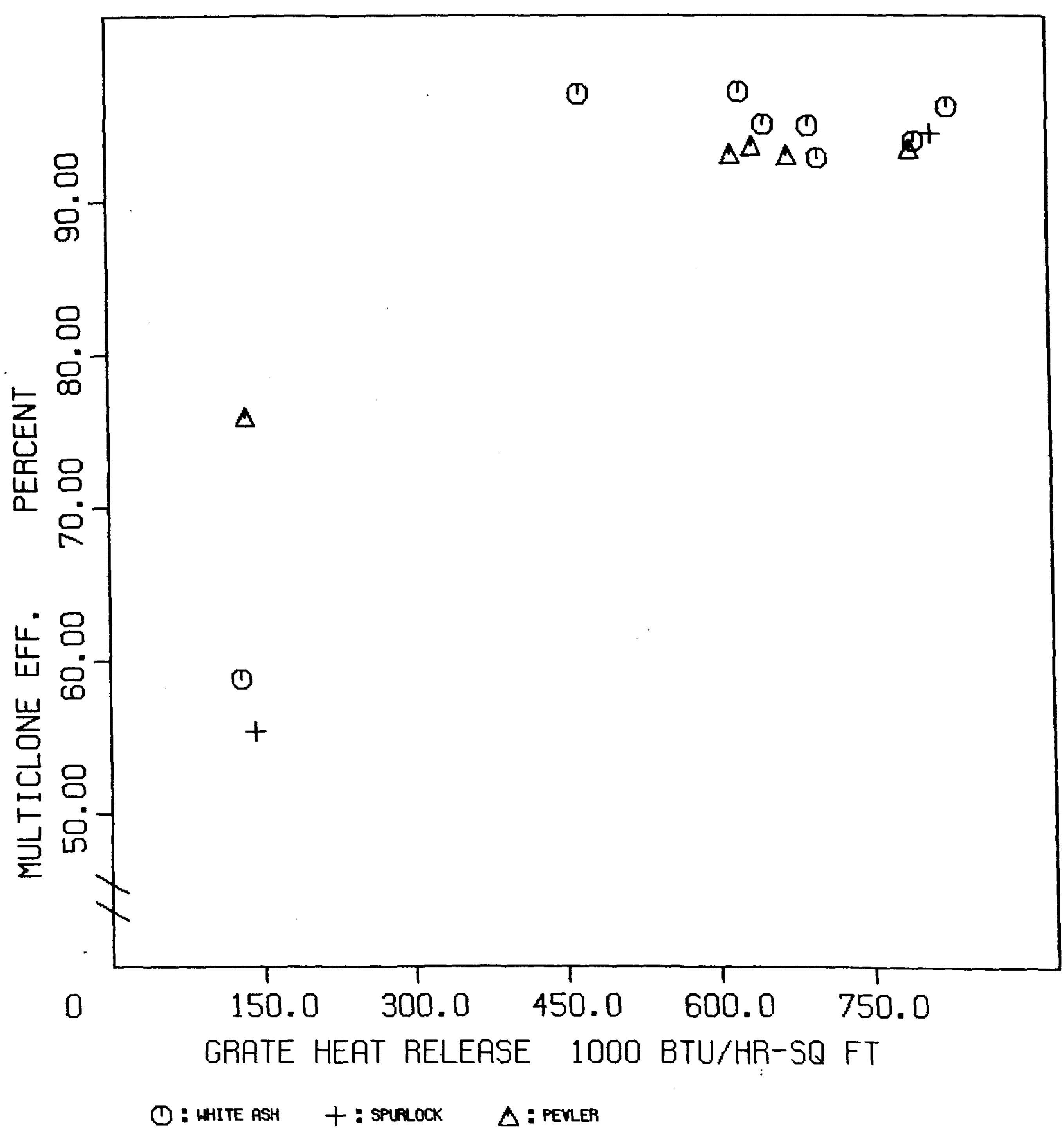


FIG. 5-25

MULTICLONE EFF. VS. GRATE HEAT RELEASE

TEST SITE G

TABLE 5-27

POLYNUCLEAR AROMATIC HYDROCARBONS
ANALYZED IN THE SITE G SASS SAMPLE

Element Name	Molecular Weight	Molecular Formula
7,12 Dimethylbenz (a) anthracene	256	$C_{20}H_{16}$
Dibenz (a,h) anthracene	278	$C_{22}H_{14}$
Benzo (c) phenanthrene	228	$C_{18}H_{12}$
3-methyl cholanthrene	268	$C_{21}H_{16}$
Benzo (a) pyrene	252	$C_{20}H_{12}$
Dibenzo (a,h) pyrene	302	$C_{24}H_{14}$
Dibenzo (a,i) pyrene	302	$C_{24}H_{14}$
Dibenzo (c,g) carbazole	267	$C_{20}H_{13}N$

5.8 DATA TABLES

Tables 5-28 through 5-31 summarize the test data obtained at Test Site G. These tables, in conjunction with Table 2-2 in the Executive Summary, are included for reference purposes.

TABLE 5-28

PARTICULATE EMISSIONS
TEST SITE G

	Test No.	Coal	% Design Capacity	O_2 %	EMISSIONS lb/10^6Btu	gr/SCF	lb/hr	Velocity ft/sec
BOILER OUTLET	02	White Ash	85	8.9	4.271	1.772	763	39.69
	03	White Ash	80	8.7	4.332	1.911	782	37.32
	04	White Ash	77	10.4	7.408	2.740	1,179	38.04
	05	White Ash	102	7.0	6.786	3.102	1,464	42.27
	06	White Ash	57	10.5	4.171	1.572	558	30.36
	07	Spurlock	17	14.6	2.139	0.482	96	16.16
	08	Spurlock	100	6.6	2.932	1.506	568	35.14
	10	White Ash	86	9.7	6.592	2.590	1,120	38.79
	16	White Ash	16	15.2	2.265	0.460	96	16.72
	17	White Ash	98	7.4	5.858	2.550	1,326	50.45
	18	Pevler	97	7.5	4.783	2.138	980	42.64
	19	Pevler	17	15.1	2.057	0.416	81	15.83
	22	Pevler	82	9.1	4.720	1.917	848	41.63
	23	Pevler	76	8.0	4.567	2.018	811	37.70
	24	Pevler	78	7.3	4.003	1.882	717	35.86
MECHANICAL COLLECTOR OUTLET	02	White Ash	85	9.9	0.222	0.085	18	63.21
	03	White Ash	80	9.2	0.220	0.093	19	62.64
	04	White Ash	77	10.0	0.221	0.085	17	62.88
	05	White Ash	102	7.6	0.274	0.120	25	65.63
	06	White Ash	57	11.0	0.129	0.046	8	50.28
	07	Spurlock	17	14.8	0.953	0.208	26	34.78
	08	Spurlock	100	6.9	0.166	0.084	18	68.19
	10	White Ash	86	9.1	0.484	0.200	42	65.87
	16	White Ash	16	15.2	0.933	0.190	20	28.70
	17	White Ash	98	7.4	0.364	0.158	34	68.65
	18	Pevler	97	7.5	0.320	0.142	32	70.96
	19	Pevler	17	15.1	0.495	0.100	10	27.57
	22	Pevler	82	9.1	0.334	0.136	29	67.62
	23	Pevler	76	8.0	0.320	0.141	27	60.42
	24	Pevler	78	7.3	0.260	0.122	24	62.61

TABLE 5-29

HEAT LOSSES AND EFFICIENCIES
TEST SITE G

	TEST NO.	DRY GAS LOSS	MOISTURE IN FUEL	H_2O FROM COMBUSTION OF H_2	COMBUSTIBLES IN FLYASH	COMBUSTIBLES IN BOTTOM ASH	TOTAL COMBUSTIBLES IN REFUSE	RADIATION FROM BOILER	UNMEASURED	TOTAL LOSSES	EFFICIENCY
WHITE ASH COAL	02	14.74	0.45	4.22	3.54	1.16	4.70	0.62	1.5	26.23	73.77
	03	13.35	0.41	4.00	3.22	0.27	3.49	0.66	1.5	23.41	76.59
	04	19.27	0.54	4.11	5.38	0.44	5.82	0.68	1.5	31.92	68.08
	05	13.25	0.80	4.48	4.81	0.52	5.33	0.52	1.5	25.88	74.12
	06	13.13	0.29	3.90	2.83	0.34	3.17	0.91	1.5	22.90	77.10
	09	14.29	0.41	4.17	5.83	0.34	6.17	0.72	1.5	27.26	72.74
	10	13.48	0.38	4.13	5.36	0.59	5.95	0.61	1.5	26.05	73.95
	15	12.91	0.42	4.14	4.81	0.89	5.70	0.60	1.5	25.27	74.73
	16	22.73	0.36	3.81	1.53	0.60	2.13	3.19	1.5	33.72	66.28
	17	13.96	0.37	4.09	5.45	0.32	5.77	0.54	1.5	26.23	73.77
SPURLOCK	07	23.21	0.26	3.89	1.43	0.14	1.57	2.92	1.5	33.35	66.65
	08	12.25	0.26	4.14	1.98	0.14	2.12	0.53	1.5	20.80	79.20
PEVLER COAL	18	13.07	0.51	4.43	3.72	1.15	4.87	0.54	1.5	24.92	75.08
	19	25.42	0.41	3.93	1.46	0.55	2.01	3.04	1.5	36.31	63.69
	20	13.02	0.47	4.28	3.89	0.79	4.68	0.67	1.5	24.62	75.38
	22	14.16	0.45	4.25	3.68	1.15	4.83	0.64	1.5	25.83	74.17
	23	12.95	0.44	4.26	3.29	0.71	4.00	0.69	1.5	23.84	76.16
	24	11.94	0.38	4.19	3.59	0.75	4.34	0.67	1.5	23.02	76.98

TABLE 5-30

PERCENT COMBUSTIBLES IN REFUSE
TEST SITE G

	Test No.	Boiler Outlet	Mechanical Collector Hopper	Mechanical Collector Outlet	Bottom Ash
WHITE ASH	02	58.1	53.91	--	12.53
	03	52.2	53.91	29.1	7.26
	04	--	56.74	28.9	11.23
	05	49.7	49.85	--	6.93
	06	47.7	49.85	--	7.11
	10	57.0	42.73	22.9	9.77
	15	--	40.65	--	14.88
	16	47.6	57.30	16.8	8.18
	17	--	57.30	28.7	7.34
	09	--	55.71	--	7.87
	Average	52.05	51.80	25.3	9.51
SPURLOCK	07	47.4	50.05	54.2	4.22
	08	--	56.65	34.6	6.02
	Average	47.4	53.35	44.4	5.12
PEVLER	18	--	51.15	29.5	13.93
	19	50.1	62.51	53.0	8.79
	20	--	57.09	--	12.32
	22	54.7	67.03	28.6	19.09
	23	50.6	57.57	28.8	13.12
	24	62.9	56.15	30.2	11.48
	Average	54.6	58.58	34.0	13.12

TABLE 5-31

STEAM FLOW AND HEAT RELEASE RATES
TEST SITE G

Test No.	% Design Capacity	Steam Flow 10^3lb/hr	Heat Input* 10^6Btu/hr	Heat Output 10^6Btu/hr	Front Foot Heat Release 10^4Btu/ft/hr	Grate Heat Release 10^3Btu/ft^2/hr	Furnace Heat Release 10^2Btu/ft^3/hr
01	92.2	69.2	103.2	82.6	1058.9	753.6	250.6
02	85.5	63.8	95.2	76.1	976.3	694.7	231.0
03	79.6	59.7	89.2	71.3	914.4	650.7	216.4
04	76.7	57.6	85.9	68.8	881.5	627.4	208.6
05	101.7	76.3	113.9	91.1	1168.0	831.3	276.4
06	57.4	43.1	64.3	51.4	659.5	469.4	156.1
07	17.3	13.0	19.4	15.5	199.2	141.8	47.1
08	99.6	74.7	111.5	89.2	1143.9	814.1	270.7
09	72.3	54.2	80.9	64.8	830.2	590.8	196.5
10	86.0	64.5	96.3	77.0	987.7	702.9	233.7
11	77.9	58.4	87.2	69.8	894.5	636.6	212.0
12	98.3	73.7	110.0	88.0	1128.6	803.2	267.1
15	87.4	65.6	97.9	78.3	1004.0	714.5	237.6
16	15.8	11.9	17.7	14.2	181.5	129.2	43.0
17	97.7	73.3	109.4	87.5	1121.8	798.3	265.5
18	97.1	72.9	108.8	87.0	1115.6	793.9	264.0
19	16.6	12.4	18.6	14.9	190.7	135.7	45.1
20	77.7	58.3	87.0	69.6	892.5	635.2	211.2
22	82.4	61.8	92.2	73.8	946.0	673.3	223.9
23	75.5	56.7	84.6	67.7	867.7	617.5	205.3
24	78.3	58.7	87.6	70.1	898.7	639.4	212.7
25	99.5	74.6	111.4	89.1	1142.1	812.8	271.6
26	77.8	58.4	87.2	69.8	894.3	636.4	212.7

*** Because there was no coal scale on Boiler G, heat input was computed as heat output divided by 0.8.**

APPENDICES

APPENDIX A

DISCUSSION OF LOW ASH COAL PROBLEM

The following discussion is taken from internal correspondence at Test Site G. In this discussion, coal A and B refer to the coals described in this report as White Ash and Spurlock respectively. Coal C refers to a coal which was never fired and which was later replaced by Pevler Coal.

> As discussed in our telephone conversation on February 26, the low ash content of test coal B (1" x 3/8") is causing problems in maintaining the proper depth of ashes (4" - 6") on the grate of the #5 boiler. We are able to maintain only 1-1/2" of ash depth with the grate moving as slow as possible. The low ash depth could cause the grate to overheat if a high steam load is maintained over an extended period of time.
>
> I realize we are in the process of testing different coals with the American Boiler Manufacturers Association, but with this low ash content, the test schedule will have to be altered.
>
> We have tested our normally stocked coal (1-1/4" x 1/4") according to the suggested first week test schedule of KVB with the exception of a 60 - 75,000 Lb/Hr swing load with normal O_2 and OFA. That test could not be run due to coal handling problems at the time.
>
> The test involving Coal B was started on Sunday, February 25 and the 15,000 and 75,000 Lb/Hr steady load tests were completed. Stack appearance at 15,000 Lb/Hr does not appear to be acceptable. Boiler controls were varied at the end of the minimum load test to reduce the smoking condition, but no change was noticed. With these two tests of Coal B completed, we plan no further testing of this low ash coal. We plan to mix the existing car of low ash coal with the coal already in the silo and the remaining cars will be unloaded at the Anchor storage stockpile. The rest of the test period for coal B will be used for testing coal A.
>
> We will have to discuss the remaining test schedule with the KVB testing group. Two cars of coal C (1/2" x 1/8" are in shipment to this facility and scheduled for testing during the week of March 10. If arrangements can be made, we would like to test at 15,000 Lb/Hr and then discontinue testing. Coal C, which is also a low ash coal, with 30 - 40% fines will also cause problems in maintaining a proper depth of ashes, but should not damage the grate at the low load.
>
> I plan to discuss these changes in testing with Jim Burlingame of KVB and will let you know of any further development.

APPENDIX B

CONVERSION FACTORS

ENGLISH AND METRIC UNITS TO SI UNITS

To Convert From	To	Multiply By
in	cm	2.540
in^2	cm^2	6.452
ft	m	0.3048
ft^2	m^2	0.09290
ft^3	m^3	0.02832
lb	Kg	0.4536
lb/hr	Mg/s	0.1260
$lb/10^6BTU$	ng/J	430
g/Mcal	ng/J	239
BTU	J	1054
BTU/lb	J/kg	2324
BTU/hr	W	0.2929
J/sec	W	1.000
J/hr	W	3600
BTU/ft/hr	W/m	0.9609
BTU/ft/hr	J/hr/m	3459
$BTU/ft^2/hr$	W/m^2	3.152
$BTU/ft^2/hr$	$J/hr/m^2$	11349
$BTU/ft^3/hr$	W/m^3	10.34
$BTU/ft^3/hr$	$J/hr/m^3$	37234
psia	Pa	6895
"H_2O	Pa	249.1
Rankine	Celsius	C = 5/9R-273
Fahrenheit	Celsius	C = 5/9(F-32)
Celsius	Kelvin	K = C+273
Rankine	Kelvin	K = 5/9R

FOR TYPICAL COAL FUEL

ppm @ 3% O_2 (SO_2)	ng/J ($lb/10^6Btu$)	0.851 (1.98×10^{-3})
ppm @ 3% O_2 (SO_3)	ng/J ($lb/10^6Btu$)	1.063 (2.47×10^{-3})
ppm @ 3% O_2 (NO)*	ng/J ($lb/10^6Btu$)	0.399 (9.28×10^{-4})
ppm @ 3% O_2 (NO_2)	ng/J ($lb/10^6Btu$)	0.611 (1.42×10^{-3})
ppm @ 3% O_2 (CO)	ng/J ($lb/10^6Btu$)	0.372 (8.65×10^{-4})
ppm @ 3% O_2 (CH_4)	ng/J ($lb/10^6Btu$)	0.213 (4.95×10^{-4})

*Federal environmental regulations express NOx in terms of NO_2; thus NO units should be converted using the NO_2 conversion factor.

APPENDIX C

CONVERSION FACTORS

SI UNITS TO ENGLISH AND METRIC UNITS

To Convert From	To	Multiply By
cm	in	0.3937
cm^2	in^2	0.1550
m	ft	3.281
m^2	ft^2	10.764
m^3	ft^3	35.315
Kg	lb	2.205
Mg/s	lb/hr	7.937
ng/J	$lb/10^6 BTU$	0.00233
ng/J	g/Mcal	0.00418
J	BTU	0.000948
J/kg	BTU/lb	0.000430
J/hr/m	BTU/ft/hr	0.000289
$J/hr/m^2$	$BTU/ft^2/hr$	0.0000881
$J/hr/m^3$	$BTU/ft^3/hr$	0.0000269
W	BTU/hr	3.414
W	J/hr	0.000278
W/m	BTU/ft/hr	1.041
W/m^2	$BTU/ft^2/hr$	0.317
W/m^3	$BTU/ft^3/hr$	0.0967
Pa	psia	0.000145
Pa	"H_2O	0.004014
Kelvin	Fahrenheit	F = 1.8K-460
Celsius	Fahrenheit	F = 1.8C+32
Fahrenheit	Rankine	R = F+460
Kelvin	Rankine	R = 1.8K

FOR TYPICAL COAL FUEL

ng/J	ppm @ 3% O_2 (SO_2)	1.18
ng/J	ppm @ 3% O_2 (SO_3)	0.941
ng/J	ppm @ 3% O_2 (NO)	2.51
ng/J	ppm @ 3% O_2 (NO_2)	1.64
ng/J	ppm @ 3% O_2 (CO)	2.69
ng/J	ppm @ 3% O_2 (CH_4)	4.69

APPENDIX D

SI PREFIXES

Multiplication Factor	Prefix	SI Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto*	h
10^{1}	deka*	da
10^{-1}	deci*	d
10^{-2}	centi*	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

*Not recommended but occasionally used

EMISSION UNITS CONVERSION FACTORS FOR TYPICAL COAL FUEL (HV = 13,320 BTU/LB)

To Obtain \ Multiply By		% Weight in Fuel		$lbs/10^6 Btu$		$grams/10^6 Cal$		PPM (Dry @ 3% O_2)		Grains/SCF. (Dry @ 12% CO_2)	
		S	N	SO_2	NO_2	SO_2	NO_2	SOx	NOx	SO_2	NO_2
% Weight In Fuel	S	1		0.666		0.370		$13.2x10^{-4}$		1.48	
	N				0.405		0.225		$5.76x10^{-4}$		.903
$lbs/10^6 Btu$	SO_2	1.50		1		(.556)		$19.8x10^{-4}$		(2.23)	
	NO_2		2.47				(.556)		$14.2x10^{-4}$		(2.23)
$grams/10^6 Cal$	SO_2	2.70		(1.8)		1		$35.6x10^{-4}$		(4.01)	
	NO_2		4.44		(1.8)				$25.6x10^{-4}$		(4.01)
PPM (Dry @ 3% O_2)	SOx	758		505		281		1		1127	
	NOx		1736		704		391				1566
Grains/SCF (Dry @ 12% CO_2)	SO_2	.676		(.448)		(.249)		$8.87x10^{-4}$		1	
	NO_2		1.11		(.448)		(.249)		$6.39x10^{-4}$		

NOTE: 1. Values in parenthesis can be used for all flue gas constituents such as oxides of carbon, oxides of nitrogen, oxides of sulfur, hydrocarbons, particulates, etc.
2. Standard reference temperature of 530°R was used.

APPENDIX F

UNITS CONVERSION FROM PARTS PER MILLION (PPM) TO POUNDS PER MILLION BTU INPUT ($LB/10^6BTU$)

$lb/10^6Btu$ = (ppm)(fuel factor, $\frac{SCF}{10^6 Btu}$) (O_2 correction, n.d.)(density of emission, $\frac{lb}{SCF}$) (10^{-6})

Fuel factor, $\frac{SCF^*}{10^6 Btu}$ = $10^6 [1.53C + 3.61H_2 + .14N_2 + .57S - .46O_2] \div (Btu/lb)$

where C, H_2, N_2, S, O_2 & Btu/lb are from ultimate fuel analysis; (a typical fuel factor for coal is 9820 $SCF/10^6Btu \pm 1000$)

O_2 correction, n.d. = $20.9 \div (20.9 - \%O_2)$

where $\%O_2$ is oxygen level on which ppm value is based;

for ppm @ 3% O_2, O_2 correction = $20.9 \div 17.9 = 1.168$

Density of emission = SO_2 - 0.1696 lb/SCF*
NO - 0.0778 lb/SCF
CO - 0.0724 lb/SCF
CH_4 - 0.0415 lb/SCF

to convert $lbs/10^6Btu$ to ng/J multiply by 430

* Standard conditions are 70°F, 29.92 "Hg barometric pressure

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-80-082a		

4. TITLE AND SUBTITLE	5. REPORT DATE / 6. PERFORMING ORGANIZATION CODE
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15. SUPPLEMENTARY NOTES IERL-RTP project officer is R.E.Hall. (*) Cosponsors are DoE (W.T.Harvey Jr.) and the American Boiler Manufacturers Assoc. EPA-600/7-78-136a,-79-041a,-130a,-147a,-80-064a and -065a are Site A,B,C,D,E,and F reports.

16. ABSTRACT The report gives results of field measurements made on a 75,000 lb/hr coal-fired spreader-stoker boiler. The effects of various parameters on boiler emissions and efficiency were studied. Parameters included overfire air, flyash reinjection, excess air, boiler load, and fuel properties. Measurements included O2, CO2, NO, NO2, SO2, SO3, HC, controlled and uncontrolled particulate loading, particle size distribution of the uncontrolled flyash, and combustible content of the ash. In addition to test results and observations, the report describes the facility tested, coals fired, test equipment, and procedures. Particulate loading on this unit averaged 5.09 lb/million Btu uncontrolled and 0.28 lb/million Btu controlled at full load. Nitric oxide emissions averaged 0.49 lb/million Btu (360 ppm) at full load.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Improvement	Air Pollution Control	13B
Boilers	Efficiency	Stationary Sources	13A
Combustion	Flue Gases	Combustion Modification	21B
Coal	Fly Ash	Spreader Stokers	21D
Field Tests	Particle Size	Particulate	14B
Dust	Nitrogen Oxides	Overfire Air	
Stokers	Sulfur Oxides	Flyash Reinjection	

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